COLORADO PIKEMINNOW AND RAZORBACK SUCKER LARVAL FISH SURVEY IN THE SAN JUAN RIVER DURING 2015

FINAL REPORT

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EXECUTIVE SUMMARY

From 19 April to 30 July 2015, five larval fish survey trips were conducted between river miles 147.9 (Shiprock, NM) and 2.9 (Clay Hills Crossing, UT) on the San Juan River. During the study period mean discharge was 1,373 cfs (225–4,110 cfs) and mean temperature was 20.5 ^{o}C (12.2–27.4 ^{o}C). A total of 293 collections were made encompassing 8,886.4 m^2 of low velocity habitat. The 293 collections contained 17,787 age-0 and 227 age-1+ fish representing six families and 15 species.

There were 24 age-0 Colorado Pikeminnow collected in 2015 between river miles 94.8 and 57.2. Colorado Pikeminnow ranged from 8.6 to 9.7 mm (total length) with all larvae developmentally being mesolarvae. Back-calculated spawning dates encompassed a 5-day period between 10 July and 14 July 2015. A total of 21 age-1+ Colorado Pikeminnow were also collected in 2015. We assumed these fish were the results of stocking efforts. The analysis of Colorado Pikeminnow (age-0) sampling-site density data, using general linear models based on mixture-model estimates (Delta (δ) and Mu (m)), showed that (δ (Year) m(.) received most (0.53) of the AIC_C weight (w_i). The second and third ranked models incorporated July flow and July temperature respectively for Mu (m). Cumulatively, the top 10 models received > 99.0% of the AIC_C weight. The estimated densities ($E(x)$) of age-0 Colorado Pikeminnow in 2015, using sampling-site density data, were significantly lower than 2014 ($P < 0.05$).

Within the habitat types, estimated densities ($E(x)$) for Colorado Pikeminnow were higher in backwaters than in near zero velocity habitat types ($P < 0.05$) with no other differences among habitat types. Colorado Pikeminnow have not been collected in run type habitats. Estimated densities in the terminus of backwaters and embayments were higher ($P < 0.05$) than those associated with the mouth.

Between the April and June sampling trips, 1,205 larval Razorback Suckers were collected between river miles 139.5 and 3.3. Ontogenetic stages of age-0 Razorback Suckers ranged from protolarvae to metalarvae and back-calculated spawning dates ranged from 19 March to 4 May 2015. Spawning by Razorback Sucker in the San Juan River has been documented for each of the last 18 years. General linear models of Razorback Sucker mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the (δ(year) μ(year)) model received most (0.50) of the AIC_C weight (w_i). The (δ(year) μ(May flow)) model was the second ranked model and received slightly less (0.47) AIC_C weight than the top model. Razorback Sucker estimated densities ($E(x)$), using sampling-site density data (1999–2015), were highest in 2015 (27.4) and lowest in 1999 (0.17). The estimated densities of Razorback Sucker were significantly higher ($P < 0.05$) in 2011–2015 compared to 1999–2001 and 2004–2009.

Within the habitats sampled estimated densities ($E(x)$) for Razorback Sucker were significantly higher in backwaters ($P < 0.05$) when compared to run, embayment, and low velocity habitat types. Estimated densities were also significantly higher ($P < 0.05$) in near zero velocity habitats compared to low velocity and run type habitats. Embayment and low velocity estimated densities were only significantly higher than run habitats. Within backwaters and embayments, there was no statistical difference of estimated densities for sampling location within those two habitat types.

In 2015, 347 age-0 Razorback Suckers were rated for opercular deformities. Fish were rated from each of the geomorphic reaches within the study area, with deformed fish found in each reach. Deformities were found bilaterally (6.6%, $n = 23$) and unilaterally (12.1%, $n = 42$). Severe deformities (a rating of 2) were found in 13 fish, with about half ($n = 6$) having bilateral deformities. The deformity rate in 2015 (18.7%) was lower than that documented in 2014 (34.1%).

During the 2015 survey, a total of 74 visitations were made to the 15 monitoring sites within the study area. The highest level of connectivity observed during 2015 was during the June survey with the lowest occurring during the late-July survey. Monitoring site collections contained 2,550 age-0 fish including 226 larval Razorback Sucker. This represents 18.8% of the 2015 Razorback Sucker total. Larval Colorado Pikeminnow were not collected within the monitoring sites in 2015. Three age-1 Colorado Pikeminnow were collected at two monitoring sites during the May survey.

During the 2015 larval survey the phase I RERI sites provided nursery habitat for larval fishes. Twenty Razorback Sucker were captured in May and at the river miles 128.6 ($n = 16$) and 127.2 ($n = 4$) sites. Of the 462 specimens collected in the RERI sites, 98.9% were native species.

INTRODUCTION

Colorado Pikeminnow, *Ptychocheilus lucius*, and Razorback Sucker, *Xyrauchen texanus,* are two endangered species of cypriniform fishes native to the San Juan River, a large tributary of the Colorado River. The decline of these and other native fishes in the San Juan River has been attributed to flow modifications, instream barriers, changes to the thermal regime, and channel simplification. In addition, the introduction of nonnative fishes may have altered predation dynamics and competition for habitat and resources.

Colorado Pikeminnow (family Cyprinidae) was listed as an endangered species by the U.S. Department of the Interior in 1974. It is endemic to the Colorado River Basin where it was once abundant and widespread (Tyus, 1991). Currently this species occupies only about 20% of its historical range (Behnke and Benson, 1983; Tyus, 1990), with the majority of the remaining Upper Basin individuals occurring in the Green River (Holden and Wick, 1982; Bestgen et al., 1998). No Colorado Pikeminnow have been reported in the Lower Basin since the 1960's (Minckley and Deacon, 1968; Minckley, 1973; Moyle, 2002).

Studies in the Upper Colorado River Basin (Yampa and Green Rivers) demonstrated that Colorado Pikeminnow spawn on the descending limb of the summer hydrograph at water temperatures between 20^{o}C and 25^{o}C (Haynes et al., 1984; Nesler et al., 1988). Larval Colorado Pikeminnow drift down river as a dispersal mechanism and appear to begin this passive movement approximately five days after hatching. The five-day time frame corresponds with the swim-up period of this fish as reported by Hamman (1981, 1986). Drift of the newly hatched larval fish counteracts upstream migrations of the adults and disperses offspring to favorable nursery habitats downstream.

Razorback Sucker (family Catostomidae) was listed as an endangered species in 1991. There are few historical San Juan River records of Razorback Sucker despite the fact that this is one of three endemic Colorado River Basin catostomids. There are anecdotal reports from the late 1800's of Razorback Sucker occurring in the Animas River as far upstream as Durango, Colorado (Jordan, 1891), but there are no specimens to substantiate this claim. The first verified record of Razorback Sucker in the San Juan River was in 1976 when two adult specimens were collected in an irrigation pond near Bluff, Utah (VTN Consolidated, Inc., and Museum of Northern Arizona, 1978).

Spawning of Razorback Sucker has been associated with the ascending limb of the spring hydrograph, peak spring discharge, and warming river temperatures. Adults congregate in riffles with cobble, gravel, and sand substrates. Spawning has been documented from mid-April to early June in the Green River at mean water temperatures of 14^{o}C (Tyus and Karp, 1990). Razorback Sucker larvae have been collected from Lake Mohave at 9.5–15.0^{o}C, indicating successful incubation of eggs at these temperatures (Bozek et al., 1990). Spawning of Razorback Sucker coincides with spawning of other native catostomids. Hybridization between Flannelmouth Sucker and Razorback Sucker has been documented where these two species co-occur (Tyus and Karp, 1990; Douglas and Marsh, 1998).

Mortality rates are substantial in the early ontogeny of fishes (Harvey,1991; Jennings and Philipp, 1994). Biotic and abiotic factors often operate simultaneously and affect the survival rates of larval fishes. Starvation, the presence and duration of important environmental conditions, and biotic interactions such as competition and predation all affect the survival of larvae (Bestgen, 1996). Early-life mortality can be especially notable in populations of slow growing fishes (Kaeding and Osmundson, 1988) such as Colorado Pikeminnow and Razorback Sucker. Abiotic factors, such as water temperature and discharge, act as cues for spawning of adult fishes but also affect growth rates, available food supplies, and mortality rates for their offspring (Miller et al., 1988).

Food production, competition for food resources, and predation, especially in limited nursery habitats, result in high mortality rates of larval fishes (Houde, 1987). These factors are compounded in modified systems with large numbers of non-native fishes. For example, non-native Red Shiner, *Cyprinella lutrensis*, preys on cypriniform larvae (Brandenburg and Gido, 1999; Bestgen and Beyers, 2006). Red Shiner can compose up to 80% of the ichthyofaunal community in nursery habitats in the San Juan River (Propst et al., 2003; Brandenburg and Farrington, 2010) and may have significant impacts on native fish populations.

To mitigate these negative effects, attempts to mimic natural flow regimes in regulated systems are used to maintain cues for activities such as spawning and migration of native fishes, create and maintain nursery habitat for larval fishes, and suppress non-native fish populations (Poff et al., 1998).

Natural flow regimes also favor the downstream displacement or drifting behavior of larval fishes and exploitation of the most advantageous feeding and rearing areas (Muth and Schmulbach, 1984; Pavlov, 1994). In many western river systems, higher spring and early summer flows increase sediment transport and turbidity and have been shown to reduce predation of larvae (Johnson and Hines, 1999). Sediment transport during high spring flows also scours substrates providing critical spawning habitat to native catostomids (Osmundson et al., 2002).

Early investigations into the reproductive success of Colorado Pikeminnow on the San Juan River, were conducted from 1991 to 2001 using larval drift nets. During that period of passive sampling, only six larval Colorado Pikeminnow were collected (Appendix A, Table A-1).

Beginning in 2002, the sampling protocol was switched to active collection of larval fishes using larval seines and a raft to navigate the San Juan River. Using this active approach a total of 364 larval Colorado Pikeminnow were collected between 2004 and 2014 (Table A-1).

Larval surveys using the same active sampling methods as that for the larval Colorado Pikeminnow survey began in 1998 on the San Juan River in an attempt to document reproduction of stocked Razorback Sucker. The 1998 survey produced the first documentation of reproduction by stocked Razorback Sucker. Razorback Sucker larvae have been documented every year since 1998 (Table A-2).

Objectives

This work was conducted as required by the San Juan River Basin Implementation Program (2015) Long Range Plan. The goals and objectives of this specific monitoring project are identified in the aforementioned document and listed below:

- 4.1.1.1 Develop and revise a Standardized Fish Monitoring Plan to assess presence, status, and trends of Colorado Pikeminnow, Razorback Sucker and fish community.
- 4.1.1.2 Analyze and evaluate monitoring data and produce Annual Fish Monitoring Reports to ensure that the best sampling design and strategies are employed.
- 4.1.2.1 Conduct larval fish sampling to determine if reproduction is occurring, locate spawning and nursery areas, and gauge the extent of annual reproduction.
- 4.1.2.5 Deposit, process, and secure San Juan River fish specimens, field notes, and associated data at an organized permanent repository.
- 4.1.7.2 Provide annual updates of the rate of opercular deformities found in Razorback Sucker.
- 4.2.3.2 Document and track trends in the use of specific mesohabitat types by larval Colorado Pikeminnow and Razorback Sucker.
- 4.2.4.1 Identify principal river reaches and habitats used by various life stages of endangered fish.
- 4.3.2.1 Monitor TNC's restoration sites.
- 4.4.1.1 Document and quantify reproduction, survival, and recruitment.
- 5.1.1.3 Provide detailed analysis of data collected to determine progress towards endangered species recovery in the San Juan River.

STUDY AREA

The San Juan River is a major tributary of the Colorado River and drains 38,300 mi.^{2} (99,198 km.^{2}) in Colorado, New Mexico, Utah, and Arizona (Figure 1). The major perennial tributaries to the San Juan River are (from upstream to downstream) Navajo, Piedra, Los Pinos, Animas, La Plata, and Mancos rivers, and McElmo Creek. In addition there are numerous ephemeral arroyos and washes that contribute relatively little flow annually but input large sediment loads during rain events.

The San Juan River is currently a 224-mile (360 km) lotic system bounded by two reservoirs (Navajo Reservoir near its head and Lake Powell at its mouth). From Navajo Dam to Lake Powell, the mean gradient of the San Juan River is 10.1 ft./mi, (1.9 m/km) but can be as high as 21.2 ft./mi. (4.0 m/km) Except in canyon-bound reaches, the river is bordered by non-native salt cedar, *Tamarix ramosissima*, Russian olive, *Elaeagnus angustifolia*, native cottonwood, *Populus fremontii*, and willow, *Salix sp*. Non-native woody plants dominate nearly all sites and result in heavily stabilized banks. Cottonwood and willow compose a small portion of the riparian vegetation.

The characteristic annual hydrographic pattern in the San Juan River is typical of rivers in the American Southwest, with large flows during spring snowmelt followed by low summer, autumn, and winter base flows. Convective storm-induced flow spikes frequently punctuate summer and early autumn base flows. Prior to operation of Navajo Dam, about 73% of the total annual San Juan River drainage discharge (based on USGS Gage # 09379500; near Bluff, Utah) occurred during spring runoff (1 March through 31 July). Mean daily peak discharge during spring runoff was 10,400 cfs (range = 3,810 to 33,800 cfs). Although flows resulting from summer and autumn storms contributed a comparatively small volume to the total annual discharge, the magnitude of storm-induced flows exceeded the peak snowmelt discharge in about 30% of the years, occasionally exceeding 40,000 cfs (mean daily discharge). Both the magnitude and frequency of these historically unregulated storm induced flow spikes were greater than those recorded in the Green or Colorado Rivers.

Operation of Navajo Dam altered the annual discharge pattern of the San Juan River. The natural flow of the Animas River ameliorated some aspects of regulated discharge by augmenting spring discharge. Regulation resulted in reduced magnitude and increased duration of spring runoff in wet years and substantially reduced magnitude and duration of spring flow during dry years. Overall, flow regulation by operation of Navajo Dam has resulted in post-dam peak spring discharge averaging about 50% of pre-dam values. Conversely, post-dam base flow increased over pre-dam base flows. Since 1992, efforts have been made to operate Navajo Dam to mimic a “natural” annual flow regime.

METHODS

Access to the river and collection localities was gained through the use of 16' (4.9 m) and 12’ (3.7 m) inflatable rafts that transported both personnel and collecting gear. There was not a predetermined number of collections per river mile or geomorphic reach for this study. Instead, collections were made in as many suitable larval fish habitats as possible within the river reach being sampled. Previous San Juan River investigations clearly demonstrated that larval fish most frequently occur and are most abundant in low velocity habitats such as pools and backwaters (Lashmett, 1993). Sampling of the entire study area was accomplished during a one-week period in which the study area is divided into an “upper” section (Shiprock, NM to Sand Island, UT) and a “lower” section [Sand Island, UT to Clay Hills, UT (Figure 1)]. Sampling trips for both portions of the study area were initiated on the same day of each month whenever possible.

Collecting efforts for larval fishes were concentrated in low velocity habitats using a 1 m x 1 m fine mesh (0.8mm) larval fish seine. Several seine hauls (between two and six) were made through an individual mesohabitat depending on the size of that habitat. Beginning in 2013, fishes collected within an individual mesohabitat were preserved by individual seine haul (as opposed to all fish preserved as a single sample). For each site sampled, the length (in meters) of each seine haul was determined in addition to the number of seine hauls per site. Mesohabitat type, length, maximum and minimum depth, substrate, and turbidity (using a Secchi disk) were recorded in the field data sheet for the particular collecting site (Figure A-1). Water quality measurements (dissolved oxygen, conductivity, specific conductance,

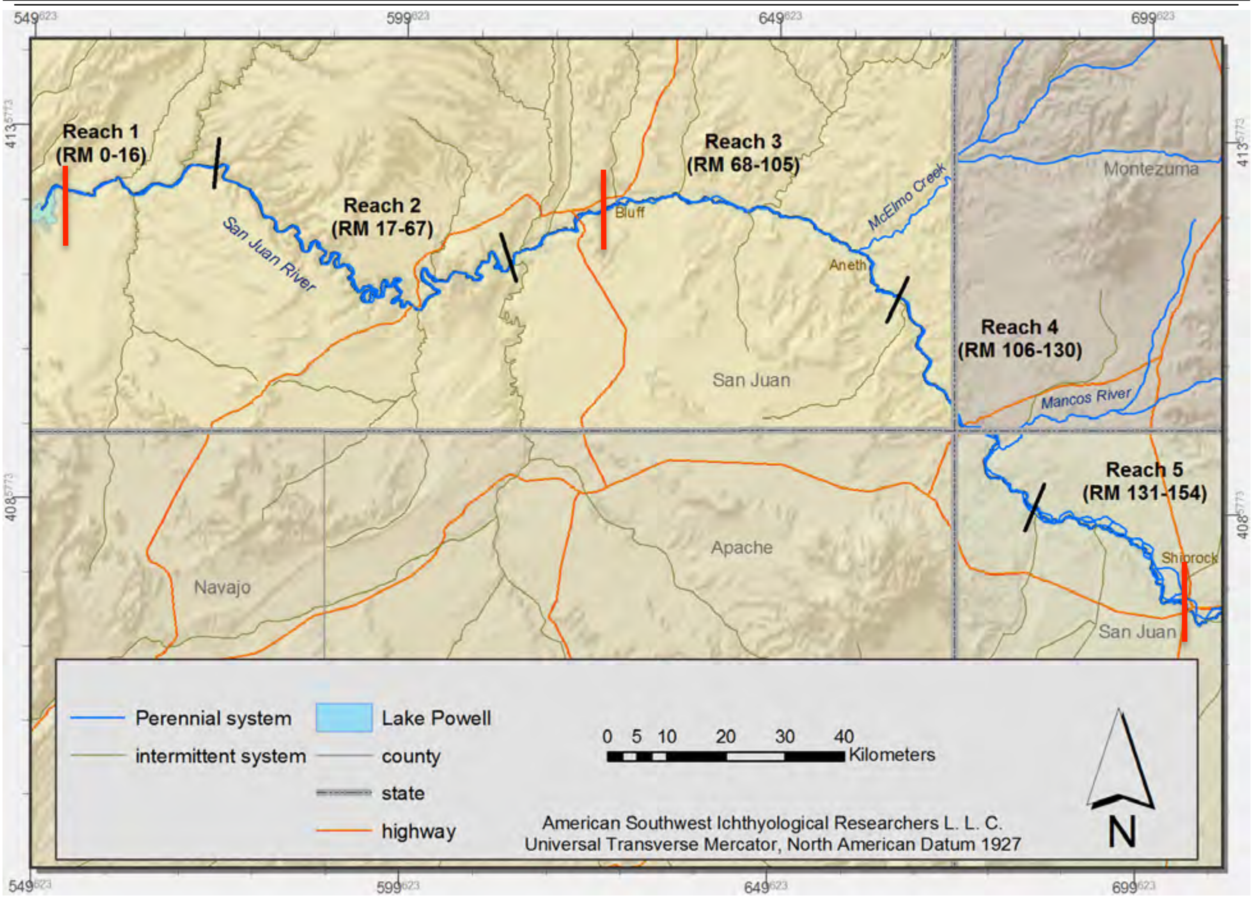


Figure 1. Map of the 2015 study area. Red bars denote upper (Shiprock, NM), middle (Sand Island, UT) and lower (Clay Hills, UT) boundaries.

pH, salinity, and temperature) were also obtained using a multi-parameter water quality meter. Habitat designations used in this report were developed for the San Juan River Basin Recovery Implementation Program's (SJRBRIP) monitoring projects (Bliesner et al., 2008). A minimum of one digital photograph was recorded at each collection site.

River mile was determined to the nearest tenth of a mile using the 2009 standardized aerial maps produced for the SJRBRIP and used to designate the location of collecting sites. In addition, geographic coordinates were determined at each site with a Garmin Geographic Positioning System (GPS) unit and were recorded in Universal Transverse Mercator (UTM) Zone 12 (NAD27). In instances where coordinates could not be obtained due to poor GPS satellite signal, coordinates were determined in the laboratory using a Geographic Information System based on the recorded river mile.

Prior to the May larval fish survey, 100,000 Razorback Sucker larvae produced at Southwestern Native Aquatic Resources and Recovery Center (SNAARC) were released at the Hogback Diversion canal. This release was part of a study to determine the effectiveness of a recently constructed weir wall that was designed to reduce the entrainment of fishes into the canal. Because the larval fish release coincided with the period of natural reproduction by adult Razorback Sucker, a means of differentiated hatchery reared and wild larvae was needed. It was assumed that some portion of the hatchery reared larvae would be collected during the larval fish surveys potentially confounding the 2015 Razorback Sucker survey results by inflating mixture-model estimates.

At SNAARC the larvae were submerged in a 350 mg/L oxytetracycline (OTC) solution for 5-6 hours. OTC leaves a fluorescent mark on the otoliths of fish larvae, which can be viewed with ultraviolet light and can be used to differentiate between wild and hatchery-produced fish. Prior to examining specimens collected during the field surveys, otoliths from known OTC marked fish, and from fish without an OTC mark, were removed, mounted and observed to verify that the OTC mark was detectable.

Using a stereo-microscope with transmitted light bases and polarized filters, otoliths were removed from 231 Razorback Sucker larvae from the May and June larval fish surveys. Using an insect pin (size 00 or 000) the top layer of tissue was removed from the area surrounding the otoliths on the left side of the head. All otoliths from the left side of the fish, the sagittal, lapillus and asteriscus were removed. Extracted otoliths from a single fish were mounted on a 25 x 75 mm glass microscope slide between two pieces of 0.10 mm diameter UTC ultra wire (Wapsi, Mountain Home, AR, USA), embedded in Crystalbond 509 (SPI supplies, West Chester, PA, USA), and covered with a 22 x 22 mm x 0.13-0.16 mm thick glass cover slip (Ted Pella, Inc., Redding, CA, USA). The wires were used to prevent otoliths from breaking when the cover slip was placed on the slide.

Mounted otoliths were viewed with a Zeiss Axioskop 2 MAT 50-1,000X compound microscope using oil immersion lenses. The otoliths were located in the microscope using the Halogen light source and then the Halogen light source was turned off and a fluorescent lamp, N HBO 103 (Carl Zeiss Light Microscopy, Gottingen, Germany) was turned on to identify otoliths that had been marked with OTC. Otoliths marked with OTC were recorded and photographed.

Beginning in 2011, ASIR researchers defined 20 monitoring sites throughout the study area in an attempt to assess persistence of backwater habitats. All but three sites were geomorphically similar and were characterized as lateral washes or canyons, which form backwaters during increased river discharge. In 2012 the two monitoring sites not located in lateral washes or canyons were excluded from analysis. In addition, two sites designated in Reach 5 were also excluded because one was fed by irrigation return water and the other was inaccessible at most discharge levels (Table A-3). Because these sites do not have perennial flow, the only habitat types encountered were either backwaters, or, after river levels have subsided, isolated pools. Due to a change in the physical characteristics, the site at river mile 24.5 (John's Canyon) was removed from the monitoring site list in 2013. Scour at the mouth of the site has led to the formation of a pool or eddy type habitat, depending on discharge; there was no backwater type habitat encountered in 2013. The 15 remaining monitoring sites were visited in each monthly survey. If suitable nursery habitats had formed in them at the time of visitation they were sampled. If they were dry or isolated, photographs were taken and field notes written detailing condition of the habitat. Conditions of monitoring sites were then related back to discharge at time of visitation.

Each of the six River Ecosystem Restoration Initiative (RERI) sites located between river miles 132.2 and 127.2 were also the subject of repeated monthly monitoring (Figure 2). Unlike the monitoring sites, these areas were only sampled if suitable nursery habitat was available. The goal of these collections was to detect the presence of fishes, regardless of age class. If a site could not be effectively sampled (e.g. too deep or swift), photos were taken and no collection was made.

All retained specimens were placed in plastic bags (Whirl-Paks) containing a solution of 95% ethyl alcohol and a tag inscribed with a unique alpha-numeric code that was also recorded on the field data sheet. Samples were returned to the laboratory where they were sorted and identified to species. Specimens were identified by personnel with expertise in San Juan River Basin larval fish identification. Stereo-microscopes with transmitted light bases and polarized light filters were used to aid in identification of larval individuals. Age-0 specimens were separated from age-1+ specimens using published literature that define growth and development rates for individual species (Auer, 1982; Snyder, 1981; Snyder and Muth, 2004). Both age classes were enumerated, measured (minimum and maximum size [mm standard length] for each species at each site), and cataloged in the Museum of Southwestern Biology (MSB), Division of Fishes at the University of New Mexico (UNM).

Results reported in this document pertain primarily to age-0 fishes. Raw numbers of age-0 and age-1+ fishes are presented in Appendix A (Tables A-4 and A-5). Scientific and common names of fishes used in this report follow Page et al. (2013) and six letter codes for species are those adopted by the San Juan River Basin Biology Committee (Table A-6). Total length (TL) and standard length (SL) were measured on all Colorado Pikeminnow and Razorback Sucker to be consistent with information gathered by the San Juan River Basin and Upper Colorado River Basin programs. Within this report, lengths of these species are given as TL.

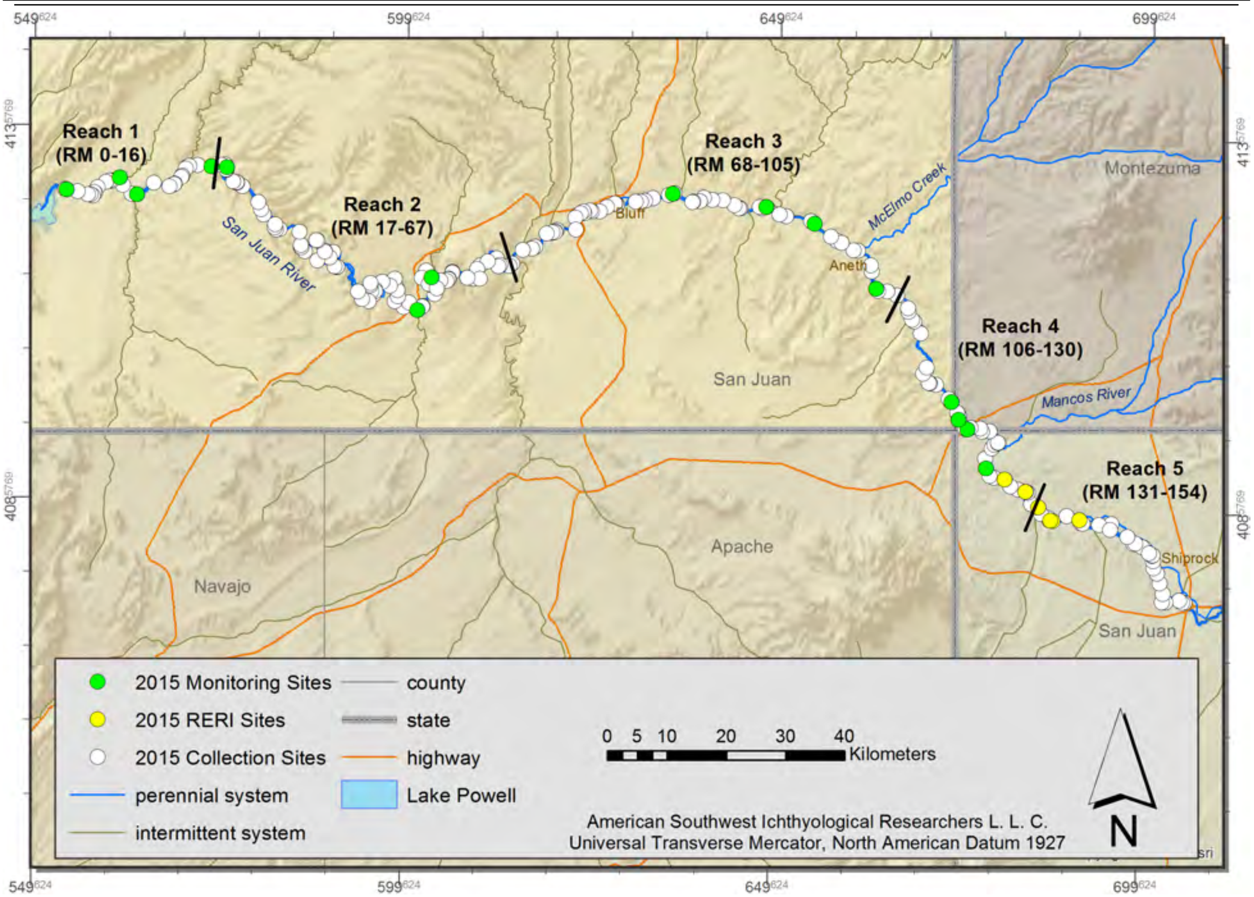


Figure 2. Map of the 2015 collection localities with RERI (yellow dots) and monitoring (green dots) sites.

The term young-of-year (YOY) can include both larval and juvenile fishes. It refers to any fish, regardless of developmental stage, between hatching or parturition and the date (1 January) that they reach age 1 (i.e., YOY = age-0 fish). Larval fish is a specific developmental (morphogenetic) period between the time of hatching and when larval fish transform to juvenile stage. The larval fish terminology used in this report follows conventions established by Snyder (1981). There are three distinct sequential larval developmental stages: protolarva, mesolarva, and metalarva. Fishes in any of these developmental stages are referred to as larvae or larval fishes. Juvenile fishes are those that have progressed beyond the metalarva stage and no longer retain traits characteristic of larval fishes. Juveniles were classified as individuals that 1) had completely absorbed their fin folds, and 2) had developed the full adult complement of rays and spines.

Modeling ecological data with multiple zeros can be particularly effective when using mixture models (e.g., combining a binomial distribution with a lognormal distribution) to estimate occurrence and abundance separately (White, 1978; Welsh et al., 1996; Fletcher et al., 2005; Martin et al., 2005). Long-term Razorback Sucker (1999–2015) Colorado Pikeminnow, and ichthyofaunal community (2003–2015) sampling-site density data were analyzed using PROC NLMIXED (SAS, 2014), a numerical optimization procedure, by fitting a mixture model using the methods outlined in White (1978). Logistic regression was used to model the probability a site was occupied, and the lognormal model was used to model the distribution of abundance given that the site was occupied. Models provided four parameter estimates for each year (δ = probability of occurrence, μ = mean of the lognormal distribution, σ = standard deviation of the lognormal distribution, and $E(x)$ = estimated density). Estimated densities incorporate both the delta and mu model estimations. For each of the long-term trend data sets, regardless of the number of model combinations examined, there is a single estimation of delta, mu, sigma, and the estimated density.

General linear models were used to incorporate covariates to model δ, μ, and σ. Covariates considered to model annual sampling-site density data for Razorback Sucker (1999–2015) were year, reach, habitat type, mean March flow and temperature, mean April flow and temperature, mean May flow and temperature, annual number stocked, cumulative number stocked, and fall monitoring captures (1+ overwinter periods) For example, if 175 individuals were collected during fall 2013 we assumed that these individuals would be available to spawn in spring 2014 (Table A-7). Covariates considered to model annual sampling-site density data for Colorado Pikeminnow (2003–2015) were year, reach, habitat type, mean June flow and temperature, mean July flow and temperature, and fall monitoring captures of adults greater than 400 mm TL. The same overwinter criteria applied to Razorback Sucker were used for Colorado Pikeminnow (Table A-8).

To facilitate a valid comparison among years and minimize excessive zeros in the model, months that produced a negligible number of specimens (< 1% of the total) were excluded from further analysis. The months considered for age-0 Razorback Sucker occurred earlier in the year (April through June) compared with the months considered for age-0 Colorado Pikeminnow (July and August). In contrast, stocked age-1+ Colorado Pikeminnow occurred throughout the typical sampling season (April–August) and so those months were included in the analysis for that life stage. Fixed effects models for each covariate were linear models ($b_0 + b_1 \times$ covariate) with the corresponding link function. These fixed effects assume that variation in the data is explained by the covariate. That is, for δ, there is no over-dispersion or extra-binomial variation, and for μ, no extra variation provided beyond the constant σ model. Random effects models were also considered for δ and μ to provide additional variation around the fitted line where a normally distributed random error with mean zero and non-zero standard deviation is used to explain deviations around the fitted covariate. Adaptive Gaussian quadrature as described in Pinero and Bates (1995) was used to integrate out these random effects in fitting the model.

The relative fit of data to various models was assessed using goodness-of-fit statistics (logLike = -2[log-likelihood] and AIC_C = Akaike's Information Criterion [Akaike, 1973; Burnham and Anderson, 2002] for finite sample sizes). Lower values of AIC_C indicate a better fit of the data to the model. Models were ranked by AIC_C values and included AIC_C weight (w_i). All AIC tables present the top models (5-10) that account for > 99.0% of the AIC_C weight (w_i). Differences among null and alternative models were assessed using a log-likelihood ratio goodness-of-fit test (Zar, 2010). For nested models, an analysis of deviance (ANODEV) was used to determine the proportion of deviance explained by the covariates for both the δ and μ models and to assess the significance ($P < 0.05$) of those values based on an F-test (Skalski et al., 1993).

Additional samples were taken in 2013, 2014 and 2015 to increase the overall sample size and provide supplemental information on habitats (i.e., habitat type, habitat location, and cover type). Field sampling efforts occurred in nine habitat types (backwater [BW], cobble shoal [CS], eddy [ED], embayment [EM], pool [PO], pocketwater [PW], run [RU], sand shoal [SS], and slackwater [SW]). Additionally, four categories were assigned to habitat depending on where the sample was taken. Shoreline (SH) indicated all samples taken along the land-water interface, open-water (OP) indicated samples taken away from the shoreline, and mouth (MO) or terminus (TR) indicated samples taken from those locations within a backwater or embayment.

Habitat-specific density data (i.e., providing information on habitat type, habitat location, and cover type) have only been available since 2013. These data provide information on the specific habitat features used by Razorback Sucker and Colorado Pikeminnow. Habitat-specific density data were also analyzed using PROC NLMIXED (SAS, 2014), using the same methods outlined previously, to assess differences among models. A simplified list of five habitats (BW, EM, RU, LV [combining CS, PW, SS, and SW], and NZV [combining ED and PO]) was used for the purpose of statistical analysis since several habitats shared nearly identical low velocity (LV) or near zero velocity (NZV) conditions. Isolated pool habitats were excluded from analysis since fish densities in confined habitats were not comparable to densities in freely accessible habitats. Similarly, habitats that were dry or not sampled were excluded from further analysis. General linear models were used to incorporate covariates to model δ, μ, and σ. Covariates considered to model habitat-specific density data were year, reach, habitat type, habitat location, and cover type. Random effects models were used with the joint binomial and lognormal likelihood to provide random errors for the Site*Year combinations. Bivariate normal errors with mean zero and covariance were assumed for each Site*Year combination. A random error (for all model combinations) was added to the logit of the binomial parameter δ, and a second random error was added to the log of the μ lognormal parameter. Adaptive Gaussian quadrature as described in Pinheiro and Bates (1995) was used to integrate out these random effects in fitting the model using the SAS NLMIXED procedure. Goodness-of-fit statistics (logLike and AIC_C) were generated to assess the relative fit of data to various models.

Hatching dates were calculated for larval Colorado Pikeminnow using the formula: $-76.7105+17.4949(L)-1.0555(L)^2+0.0221(L)^3$ for larvae under 22 mm TL, where L = length (mm TL). For specimens 22–47mm TL the formula A = -26.6421+2.7798L is used. Spawning dates were then calculated by adding five days to the post-hatch ages to account for incubation time at 20–22^{o}C (Nesler et al., 1988). Hatch dates of Razorback Sucker larvae were calculated by subtracting the average length of larvae at hatching (8.0 mm TL) from the total length at capture divided by 0.3 mm (Bestgen et al., 2002), which was the average daily growth rate of wild larvae observed by Muth et al. (1998) in the Green River UT. The back-calculated hatching formula was only applied to proto- and mesolarvae as growth rates become much more variable at later developmental stages (Bestgen, 2008). Spawning dates for Razorback Sucker are then calculated once hatching dates have been established using the negative exponential equation $y = 1440.3e^{-0.109x}$ (Bestgen et. al., 2011) where y is the temperature dependent incubation time (in hours), *e* is the base of the natural logarithm, and x is the mean daily temperature on the hatching date.

This study was initiated prior to spring runoff and completed in the middle of the summer season (early August). Daily mean discharge during the study period was acquired from U.S. Geological Survey Gages near Four Corners, CO (#09371010) and near Bluff, UT (#09379500). Near Bluff discharge and temperature were used for all data analysis in this report except for back-calculated spawning dates of Colorado Pikeminnow in which Four Corners discharge and temperature were used. Temperature data (mean, maximum, minimum) were taken at the state highway 160 bridge crossing in Colorado (river mile 119.2) and near Bluff, UT (river mile 52.0).

RESULTS

2015 Summary

The 2015 San Juan River larval fish survey encompassed a four-month period from 19 April to 30 July 2015. Five trips were conducted from river mile 147.9 (Shiprock, New Mexico) to river mile 2.9 (Clay Hills Crossing, Utah). During the study period, mean daily discharge and water temperature were 1,912 cfs (413–8,120 cfs) and 20.0^{o}C (15.1–25.6^{o}C). There were no large spring releases out of Navajo Dam in 2015 yet discharge in the San Juan River exceeded 5,000 cfs for 11 days and 8,000 cfs for two days during the study period (Figure 3). Fluctuations in discharge in the San Juan River during the study period were a result of spring runoff in the Animas River and North American Monsoonal driven rain events.

During the 2015 larval fish survey, 293 collections were made in zero and low velocity habitats encompassing an area of 8,886.4 m^2. Collections resulted in the capture of 18,014 age-0 and age-1+ fishes representing six families and 16 species (Tables A-4 and A-5). Age-0 fish were collected in each of the five surveys (April–late July) and accounted for 98.7% of the overall catch (n = 17,787). The two July sampling trips accounted for just 7.4% (n = 1,310) of the age-0 catch. Between 2003 and 2014, these two July trips have produced an average of about 38,000 age-0 fish.

Colorado Pikeminnow

2015 Summary

There were 24 larval Colorado Pikeminnow collected in 2015 between river miles 94.8 and 57.2. Colorado Pikeminnow was collected during the late July survey at five discrete localities (Figure 4). Spawning by Colorado Pikeminnow in the San Juan River has been documented in eight of the last 13 years, and five of the last six. Colorado Pikeminnow ranged in size from 8.6 to 9.7 mm TL. Developmentally, all larval Colorado Pikeminnow were flexion mesolarvae (Table A-9). Back-calculated spawning dates covered a five-day period between 10 and 14 July 2015 (Figure 5). Mean temperature and discharge during this period were 22.0°C (20.6–23.0°C) and 2,824 cfs (2,400–3,470 cfs). A total of 21 age-1+ Colorado Pikeminnow were also collected in 2015. We assumed these fish were the result of augmentation efforts.

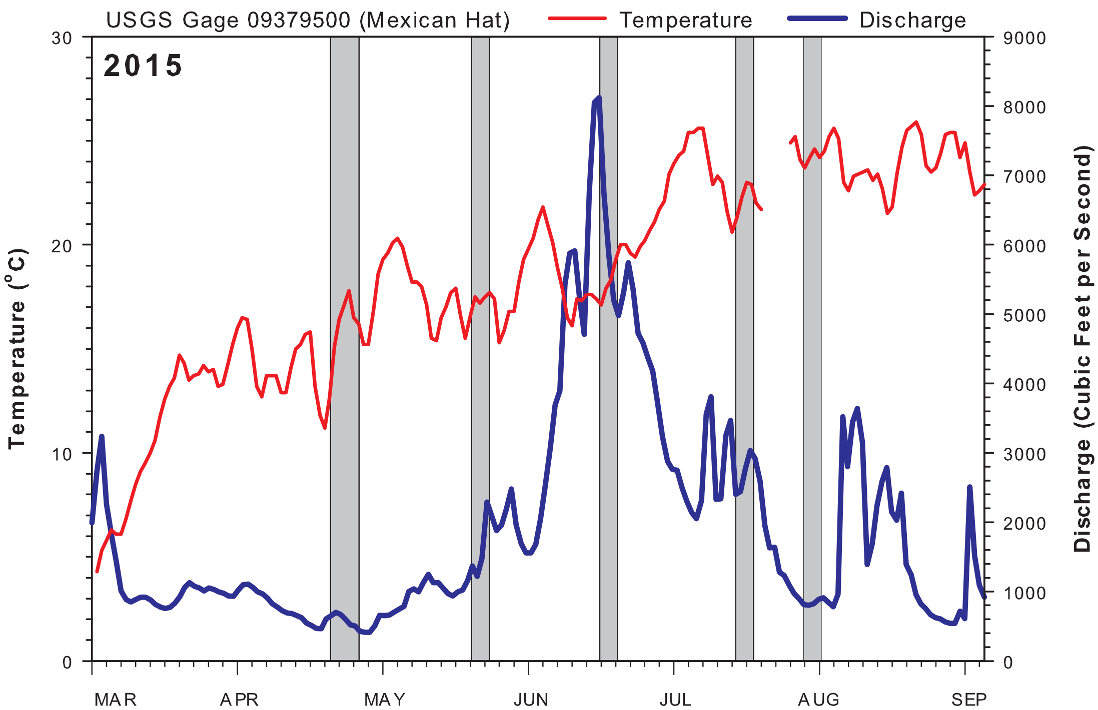


Figure 3. Discharge (cfs) and temperature (°C) in the San Juan River during the 2015 sampling period. Grey vertical bars denote individual collecting trips.

Colorado Pikeminnow (age-0)

Sampling-site density data

The analysis of Colorado Pikeminnow (age-0) sampling-site density data showed that the (δ (Year) m(.) received the most AIC_C weight (w_i) **(**Table 1). Cumulatively, the top ten models received > 99.0% of the AIC_C weight. The second and third ranked models incorporated July flow and July temperature respectively for Mu (m). Estimations of Mu (m) increased with higher July discharge and decreased with higher July temperatures.

The estimated densities ($E(x)$) of Colorado Pikeminnow in 2015 using sampling-site density data (2003–2015) was significantly lower than 2014 ($P < 0.05$), but were not statistically different than any other preceding year in which multiple Colorado Pikeminnows were collected (Figure 6). Estimated density, with 95% confidence intervals, could not be computed in 2009 since there was only a single non-zero value recorded which precluded mixture-model estimation of s. Simple estimates of mean densities, using the method of moments, illustrated their close similarity with estimated densities over time. The greatest deviation between these two density estimations was in 2015, with simple estimates being slightly higher than estimated densities.

During the study period, Colorado Pikeminnows have been collected in Reaches 4–1. There is no statistically significant difference ($P < 0.05$) among those reaches that have contained Colorado Pikeminnows (Figure 6).

Habitat type and location

All habitat data between 2003–2015 was post-processed to generate five habitat categories (see Methods for definition of condensed habitat types). During the study period, larval Colorado Pikeminnow have been collected in backwaters, embayments, near zero velocity, and low velocity habitat types. Colorado Pikeminnow has not been collected in a run type habitat (Figure 7). Within the habitat types that have contained Colorado Pikeminnow, estimated densities ($E(x)$) were significantly higher in backwaters ($P < 0.05$) than in near low velocity habitats (Figure 7).

Within backwaters and embayments, there was little difference in estimated densities within the location sampled. However, estimated densities in the terminus of backwaters and embayments were significantly higher ($P < 0.05$) than those associated with the mouth (Figure 7).

2015 trip and reach

Larval Colorado Pikeminnow were collected during the late-July survey in Reaches 3 and 2 between river miles 94.8 and 57.2 (Figure 8). All larvae were flexion mesolarvae; a relatively young life-stage. Within Reach 3, 22 larval Colorado Pikeminnow were collected in four localities while Reach 2 had two individuals collected from a single location. These numbers are in contrast to the 2014 results in which Colorado Pikeminnow was found between river miles 116.9 and 3.2 (Reaches 4–1). In 2014, the mid-July survey produced nearly 99.0% of the Colorado Pikeminnow larvae collected with nearly half of all collections containing Colorado Pikeminnow larvae.

Colorado Pikeminnow (age-1+)

Sampling-site density data

The analysis of Colorado Pikeminnow (age-1) sampling-site density data showed that the (δ (Year) m (Year.) model received the most AIC_C weight (w_i) (Table 2). The second ranked model incorporated Year for Delta (δ) and null for Mu (μ). Together these two models received > 99.9% of the AIC_C weight. The estimated densities ($E(x)$) of age-1 Colorado Pikeminnow in 2015 using sampling-site density data (2003–2015) were significantly lower ($P < 0.05$) than 2005, 2007–2010, 2012 and 2014 (Figure 9). Estimated densities ($E(x)$) in 2015 were not statistically higher than any preceding year. Even with the drop in 2015 estimated densities, the overall trend for captures of age-1 Colorado Pikeminnow has been relatively stable between 2003 and 2015 despite a wide range of environmental conditions. This stability is likely the result of a large number of Colorado Pikeminnow being annually stocked into the San Juan River during this time.

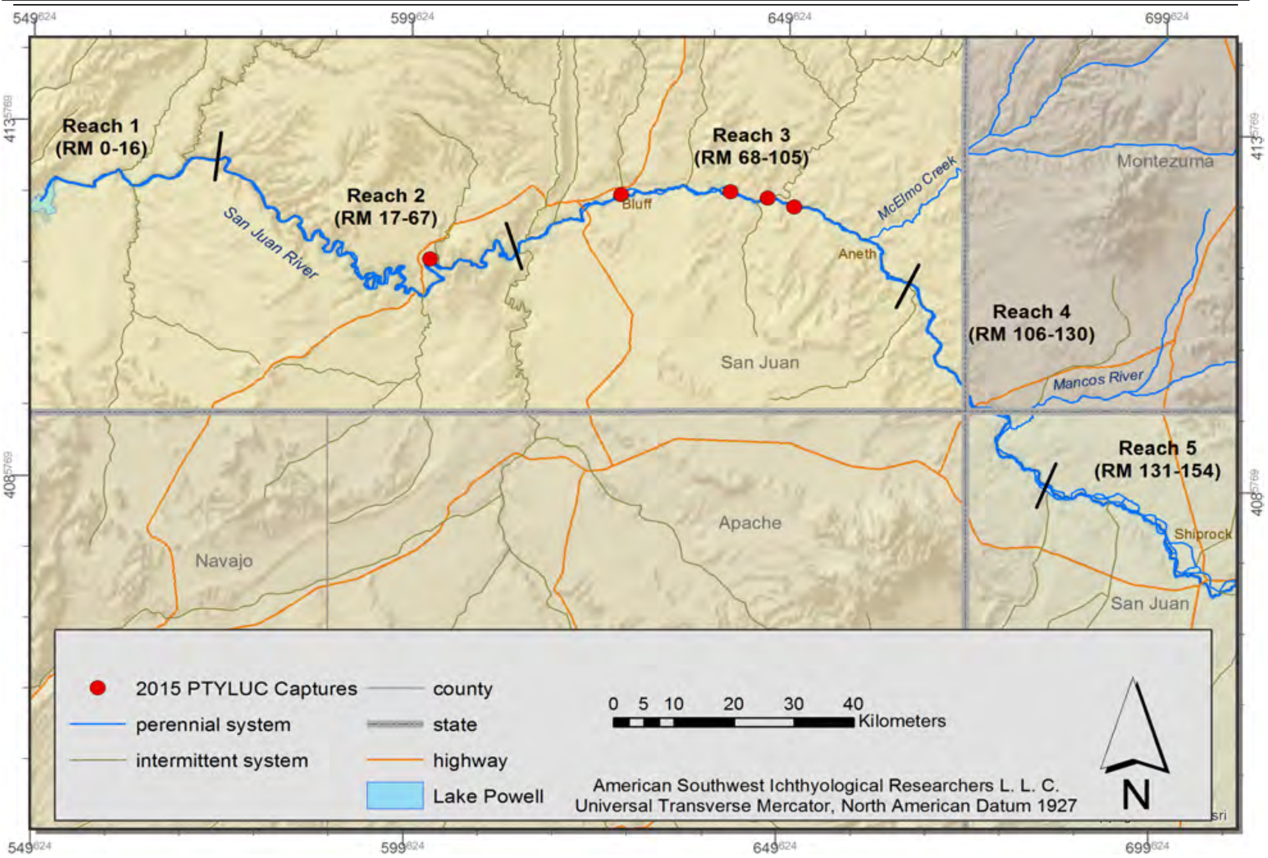


Figure 4. Map of the 2015 age-0 Colorado Pikeminnow collection localities.

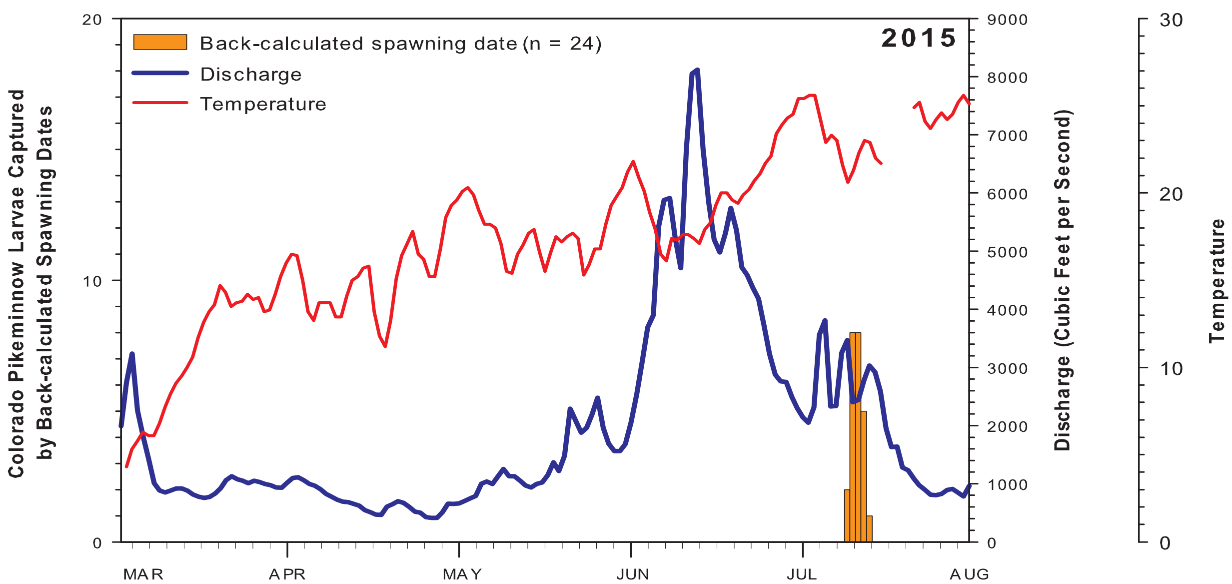
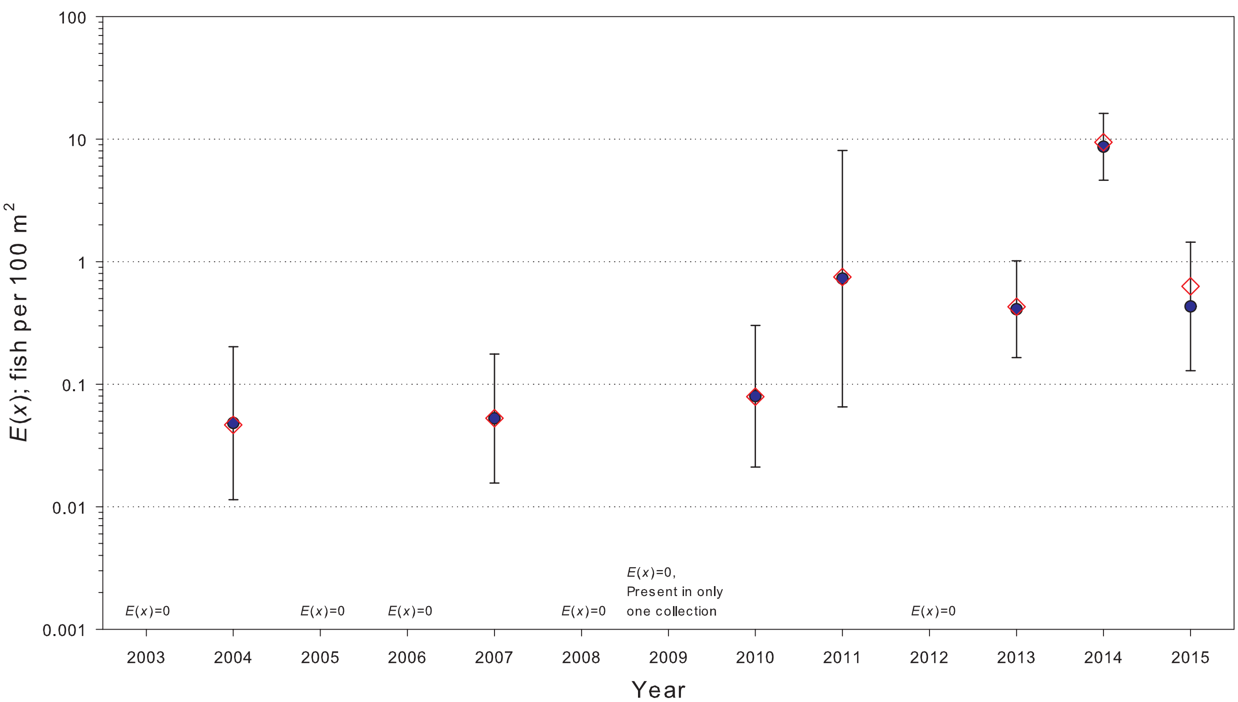


Figure 5. Back-calculated spawning dates for Colorado Pikeminnow plotted against discharge and water temperature.

Table 1. General linear models of Colorado Pikeminnow (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2015) and covariates, allowing for random effects (*R*). Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) m(.)	15	435.45	465.76	0.531
δ(Year) m(July flow)	17	434.39	468.79	0.117
δ(Year) m(July temp)	17	434.50	468.90	0.110
δ(Year) m(June flow)	17	435.17	469.57	0.079
δ(Year) m(July flow+*R*)	18	433.72	470.16	0.059
δ(Year) m(July temp.+*R*)	18	433.95	470.40	0.052
δ(Year) m(June flow+*R*)	18	434.05	470.50	0.050
δ(June flow +*R*) m(June flow+*R*)	9	462.94	481.06	<0.001
δ(July temp. +*R*) m(July temp.+*R*)	9	463.20	481.31	<0.001
δ(June temp.+*R*) m(June temp.+*R*)	9	463.46	481.58	<0.001

[1] δ = probability of occurrence
[2] μ = mean of the lognormal distribution
[3] = Model variables included year, reach, habitat type, mean June flow and temperature, mean July flow and temperature, and fall monitoring captures (400+mm TL).
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model



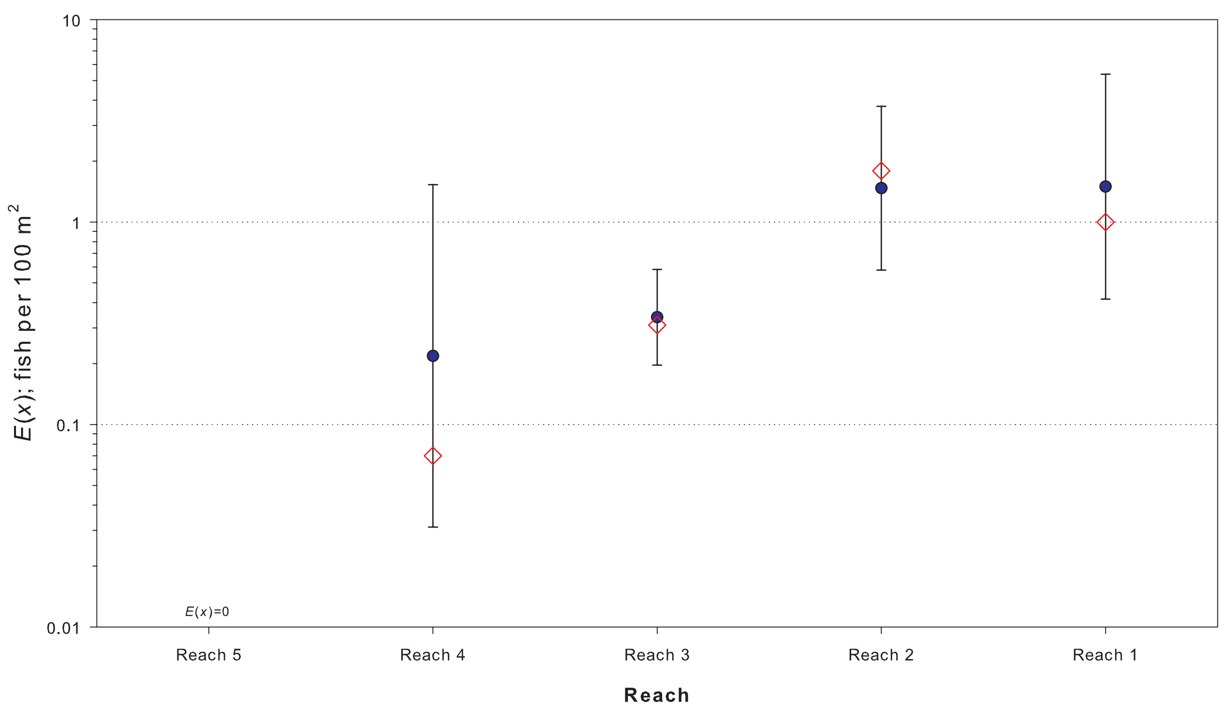


Figure 6. Colorado Pikeminnow (age-0) mixture-model estimates ($E(x)$) using sampling-site density data by year (top graph) and by reach (bottom graph). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

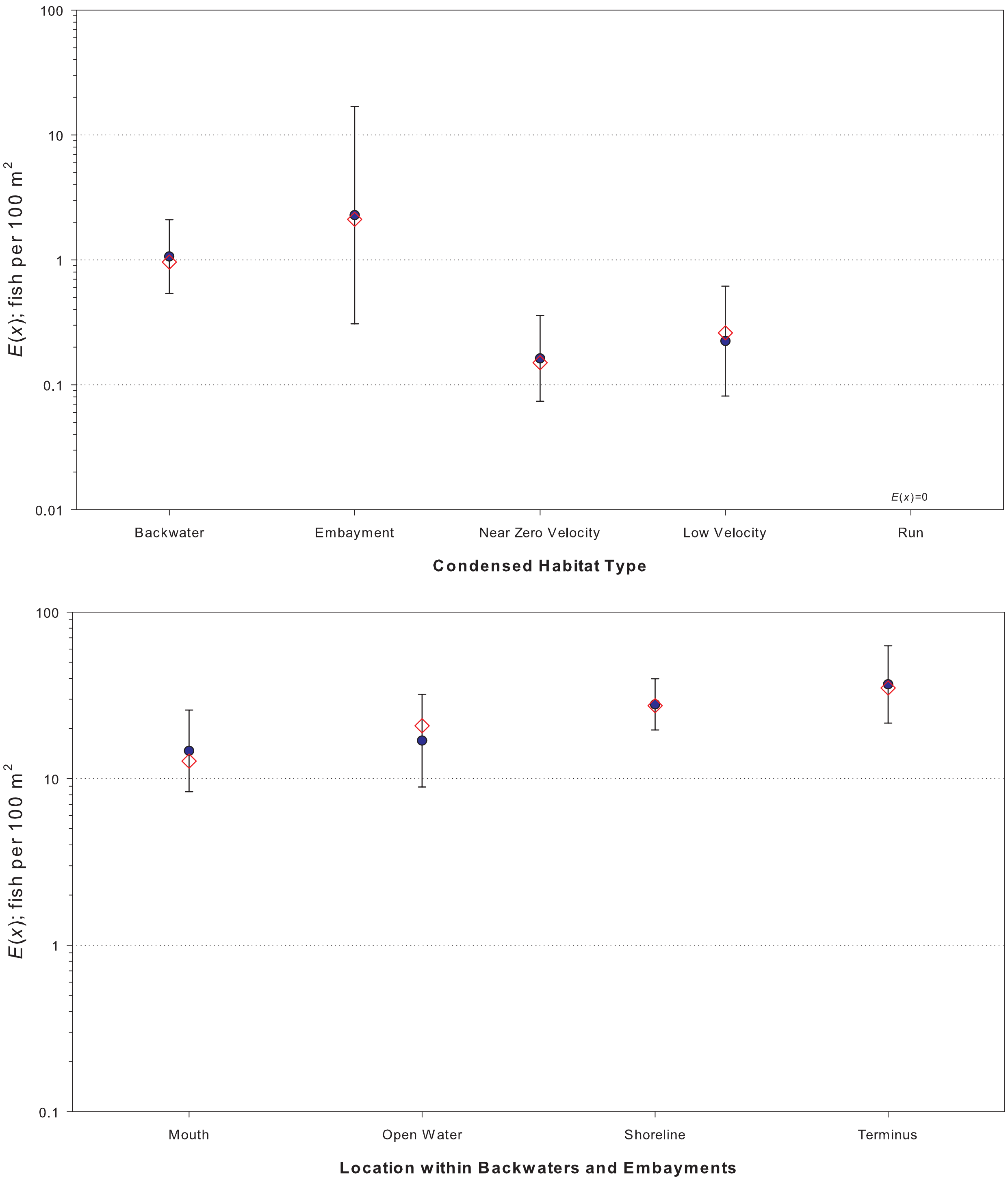


Figure 7. Colorado Pikeminnow (age-0) mixture-model estimates ($E(x)$), using sampling-site density data (2013–2015) and habitat covariates, for habitat type (top graph) and location within backwaters and embayments (bottom graph). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

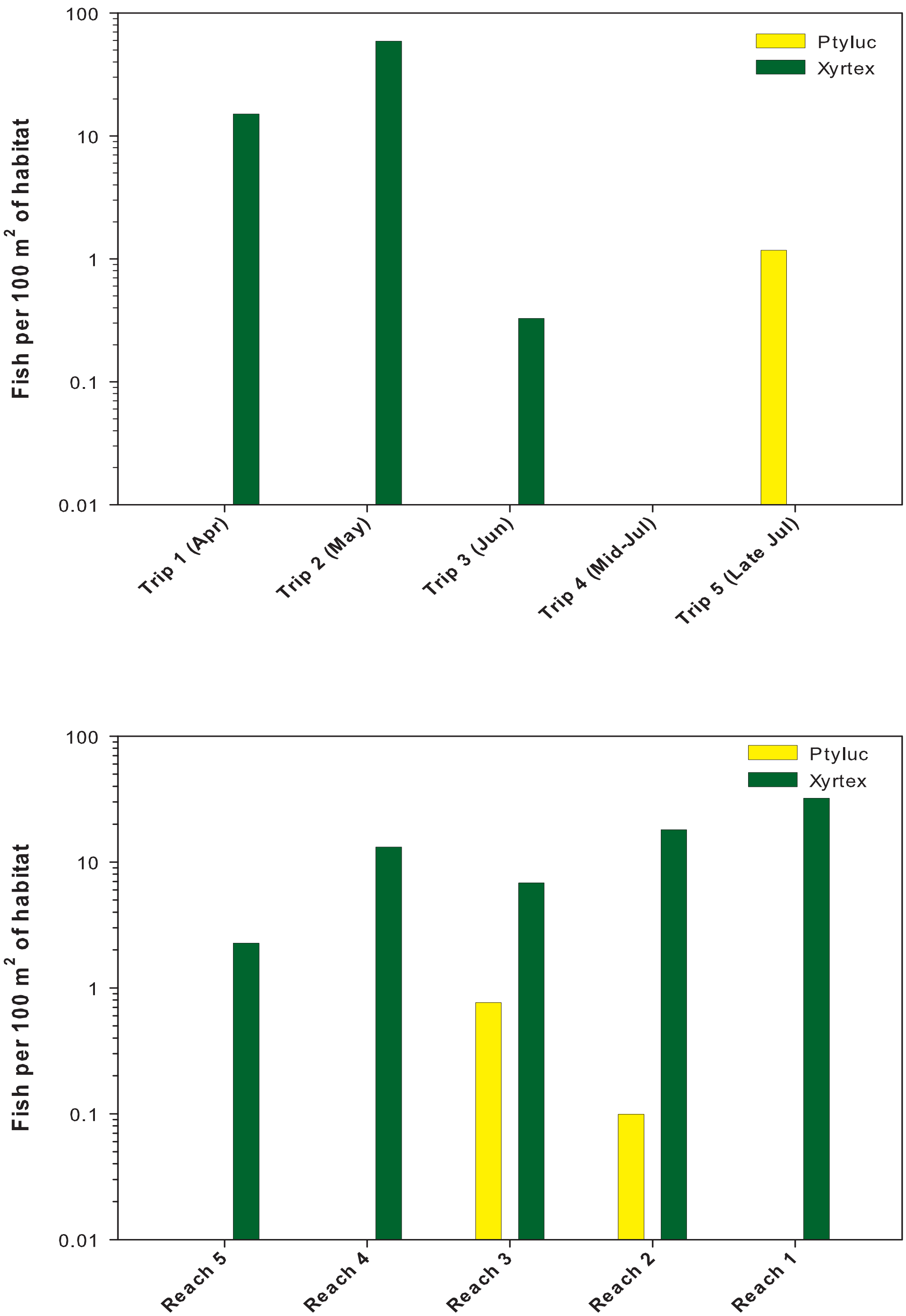


Figure 8. Density (fish per 100 m^2 of area sampled) of age-0 Colorado Pikeminnow (Ptyluc) and Razorback Sucker (Xyrtex) by trip (top graph) and reach (bottom graph) during the 2015 survey.

Table 2. General linear models of Colorado Pikeminnow (age-1+) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2015). Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	39	3,146.08	3,224.91	0.671
δ(Year) μ(.)	15	3,196.20	3,226.33	0.329
δ(Habitat) μ(Habitat)	18	3,205.71	3,241.89	<0.001
δ(Habitat) μ(.)	8	3,236.52	3,252.56	<0.001
δ(Reach) μ(Reach)	15	3,234.57	3,264.69	<0.001

[1] δ = probability of occurrence
[2] μ = mean of the lognormal distribution
[3] = Model variables included year, reach and habitat type.
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

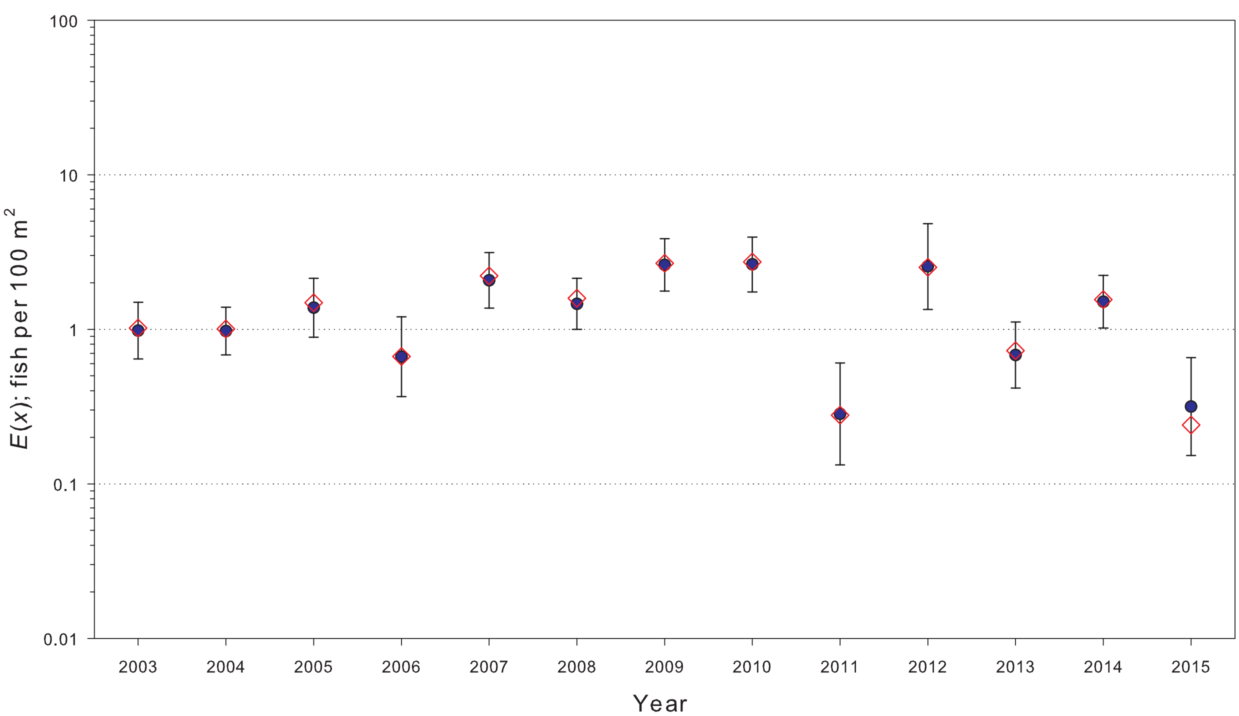


Figure 9. Colorado Pikeminnow (age-1+) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Razorback Sucker (age-0)

2015 Summary

For the eighteenth consecutive year, spawning by Razorback Sucker was documented in the San Juan River. Age-0 Razorback Sucker were collected during the April and May surveys and included ontogenetic stages that ranged from protolarvae to metalarvae (size range = 9.6–26.0 mm TL [Table A-10]). Razorback Sucker was widely distributed occurring between river miles 139.5 and 3.2, and was present in 72 of the 293 collections (Figure 10). Back-calculated spawning dates were from 19 March to 4 May 2015 (Figure 11). Mean temperature and discharge during this period was 16.0 ^{o}C (11.2–20.3) and 794 cfs (413–1,130).

Sampling-site density data

General linear models of Razorback Sucker mixture-model estimates (Delta (δ) and Mu (μ)) revealed that the (δ(year) μ(year)) model received most of the AIC_C weight (w_i) despite having the most parameters (Table 3). The (δ(year) μ(May flow)) model was the second ranked model and received slightly less AIC_C weight than the top model. Together the two top models received nearly 98.0% of the AIC_C weight. The covariate (May flow) accounted for 33.1% of the deviance explained by the μ(Year) over the null μ(.) model ($P = 0.002$). Estimations of Mu (μ) decreased as May discharge increased.

Razorback Sucker estimated densities ($E(x)$), using sampling-site density data (1999–2015), were highest in 2015 (27.4) and lowest in 1999 (0.17). The estimated densities of Razorback Sucker were significantly higher ($P < 0.05$) in 2011–2015 compared to 1999–2001 and 2004–2009 (Figure 12). The 2015 data provides further evidence of an increasing trend in densities over time, as well as a measure of stability that was not present during the early years (1999-2005) of this study. Simple estimates of mean densities, using the method of moments, were similar to estimated densities for most the years plotted. The greatest deviation occurred in 2009 and 2012. Simple estimates were higher than estimated densities for both 2009 and 2012.

Among reaches, estimated densities were highest in Reach 1 ($P < 0.05$) between 1999 and 2015, with no significant differences between Reaches 5–2 (Figure 12). The lack of a statistical difference in the four upstream reaches is a result of increasing densities in Reaches 5 and 4, rather than a drop in densities in the next two downstream reaches. This suggests Razorback Sucker adults are becoming more abundant and established higher up in the system.

Habitat type and location

Within the habitats sampled between 1999 and 2015, estimated densities ($E(x)$) were significantly higher in backwaters ($P < 0.05$) when compared to run, embayment, and low velocity habitat types (Figure 13). Estimated densities were also significantly higher ($P < 0.05$) in near zero velocity habitats compared to low velocity and run type habitats. Embayment and low velocity estimated densities were only significantly higher than run habitats. Within backwaters and embayments, there was no statistical difference of estimated densities for sampling location within those two habitat types (Figure 13).

Ontogenetic stages

Three ontogenetic stages (protolarvae, mesolarvae and metalarvae) of Razorback Sucker were collected in 2015. During the April survey protolarvae and mesolarvae were found in Reaches 4–1. The following month, protolarvae were found in every reach except Reach 3, mesolarvae were found throughout the study area, and metalarvae were found in Reaches 2 and 1. Finally, during the June survey, mesolarvae were present in Reaches 3–1 with metalarvae found at one locality in Reach 4 (Figure 14). Similar to previous surveys, the majority (80.8%) of larval Razorback Sucker collected in 2015 were mesolarvae.

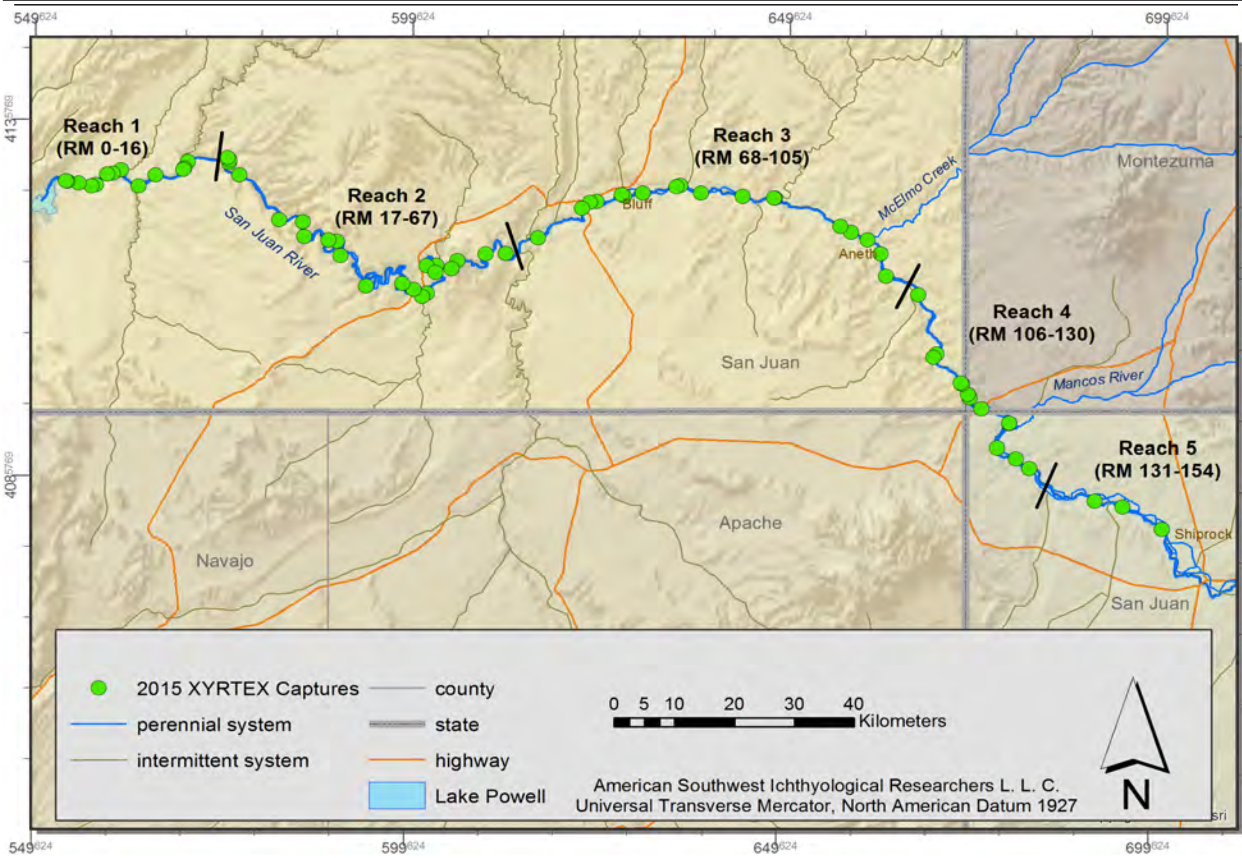


Figure 10. Map of the 2015 age-0 Razorback Sucker collection localities.

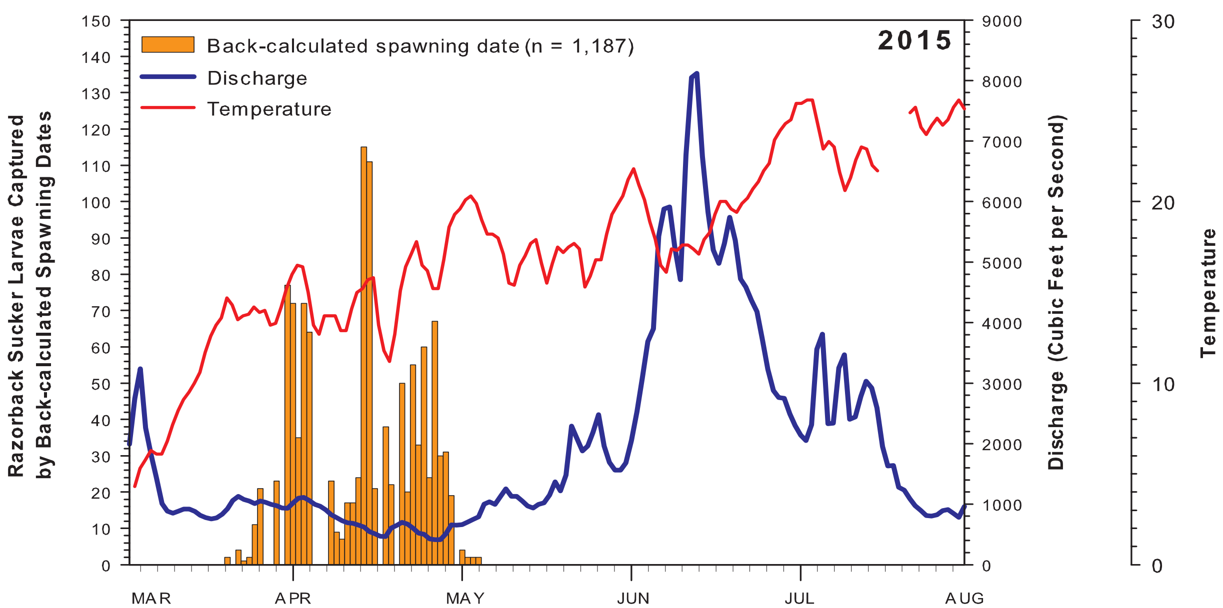
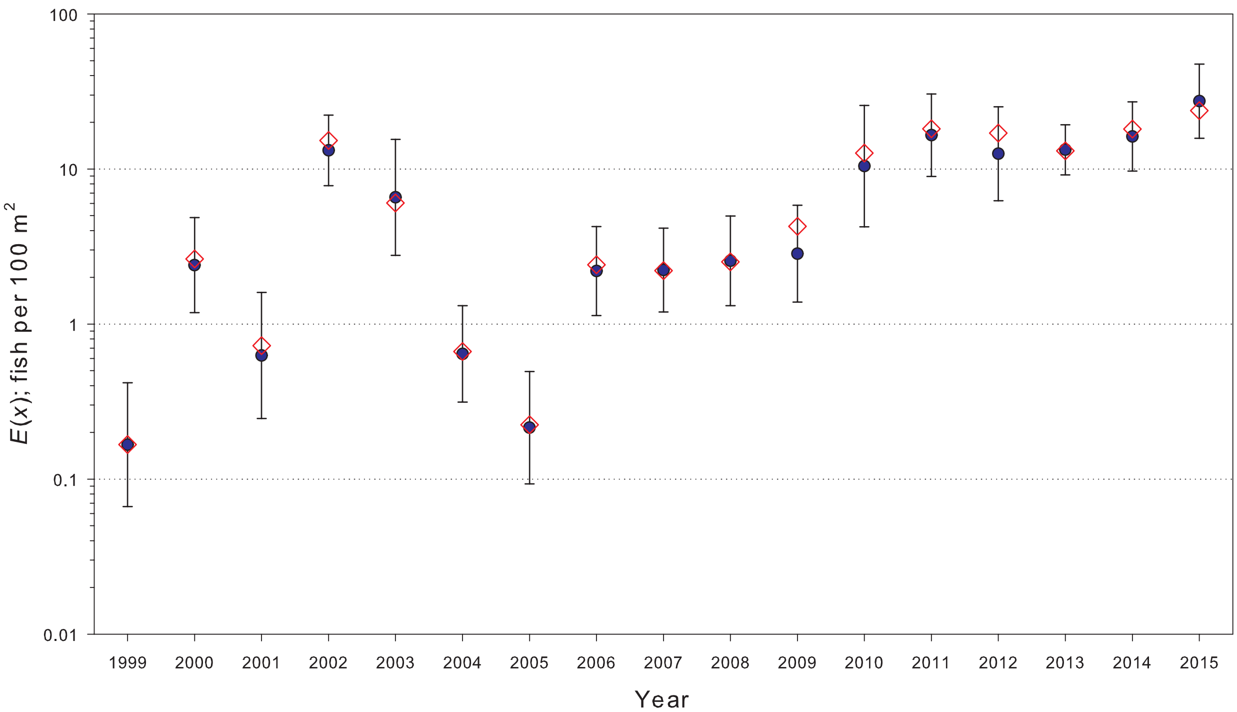


Figure 11. Back-calculated spawning dates for Razorback Sucker plotted against discharge and water temperature.

Table 3. General linear models of Razorback Sucker (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (1999–2015) and covariates allowing for random effects (*R*). Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	51	3,549.29	3,653.15	0.504
δ(Year) μ(May flow)	21	3,610.95	3,653.27	0.474
δ(Year) μ(May flow+*R*)	22	3,615.57	3,659.92	0.017
δ(Year) μ(Cum.Stock)	21	3,622.10	3,664.42	0.002
δ(Year) μ(Monitor)	21	3,622.91	3,665.23	0.001
δ(Year) μ(Cum.Stock+*R*)	22	3,621.39	3,665.74	0.001
δ(Year) μ(Monitor+*R*)	22	3,621.99	3,666.34	0.001
δ(Year) μ(April flow)	21	3,627.56	3,669.88	<0.001
δ(Year) μ(April flow+*R*)	22	3,625.89	3,670.24	<0.001
δ(Year) μ(May temp+*R*)	22	3,626.36	3,670.72	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach, habitat type, mean March flow and temperature, mean April flow and temperature, mean May flow and temperature, annual number stocked, cumulative number stocked (Cum.Stock), and fall monitoring captures (Monitor)
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model



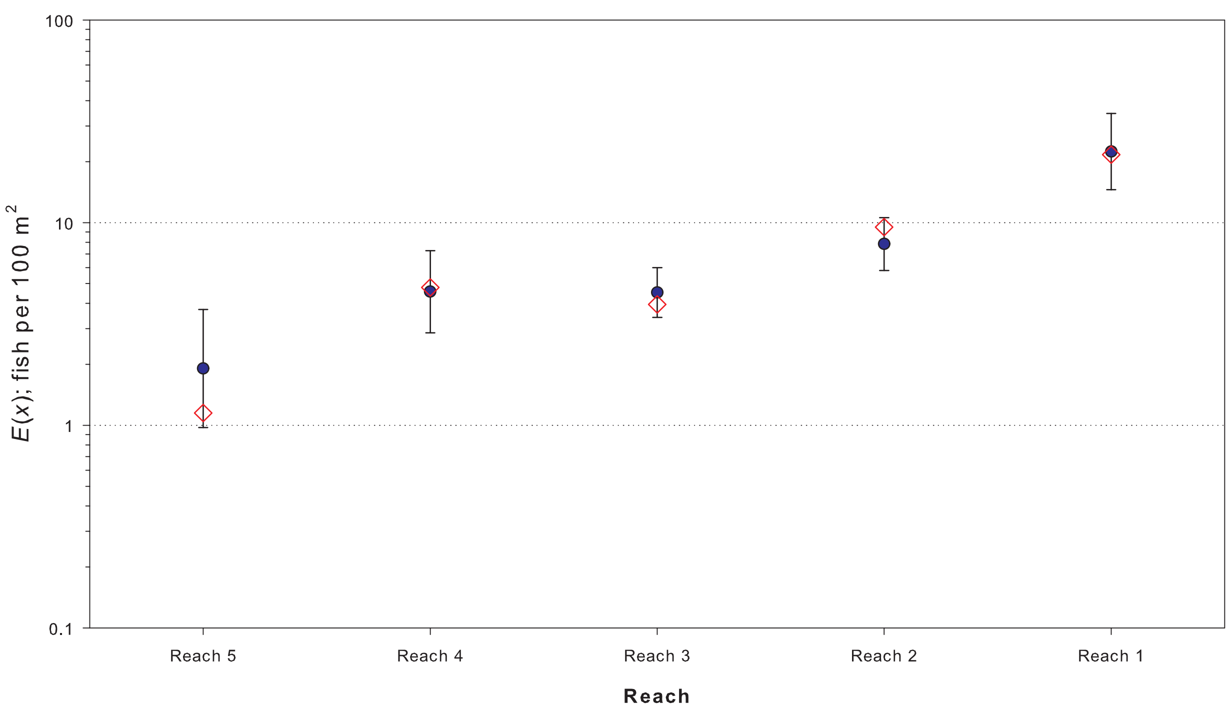


Figure 12. Razorback Sucker (age-0) mixture-model estimates ($E(x)$) using sampling-site density data by year (top graph) and reach (bottom graph). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

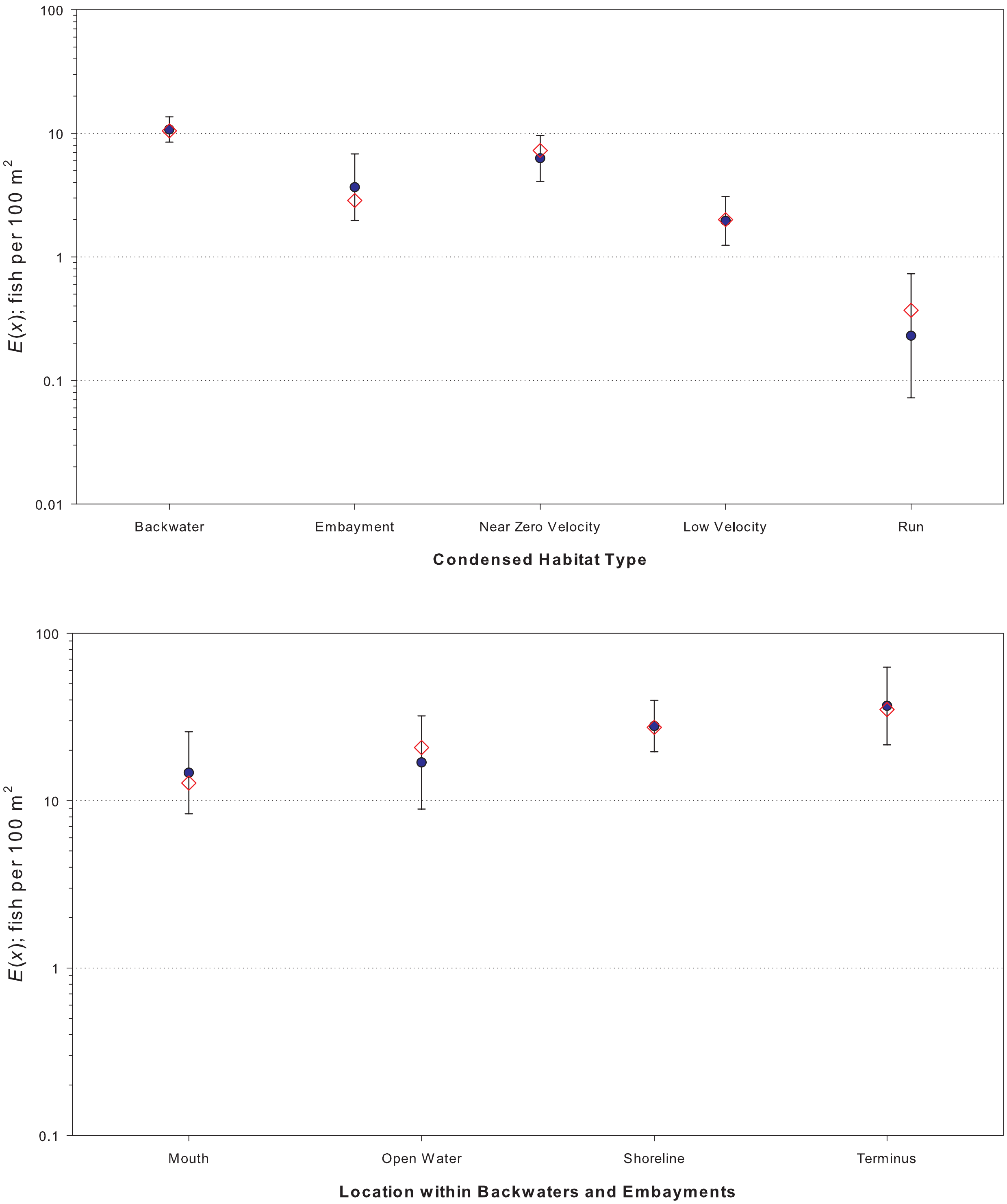


Figure 13. Razorback Sucker (age-0) mixture-model estimates ($E(x)$), using sampling-site density data (2013–2015) and habitat covariates, for habitat type (top graph) and location within backwaters and embayments (bottom graph). Solid circles indicate estimates and bars represent 95% confidence intervals.

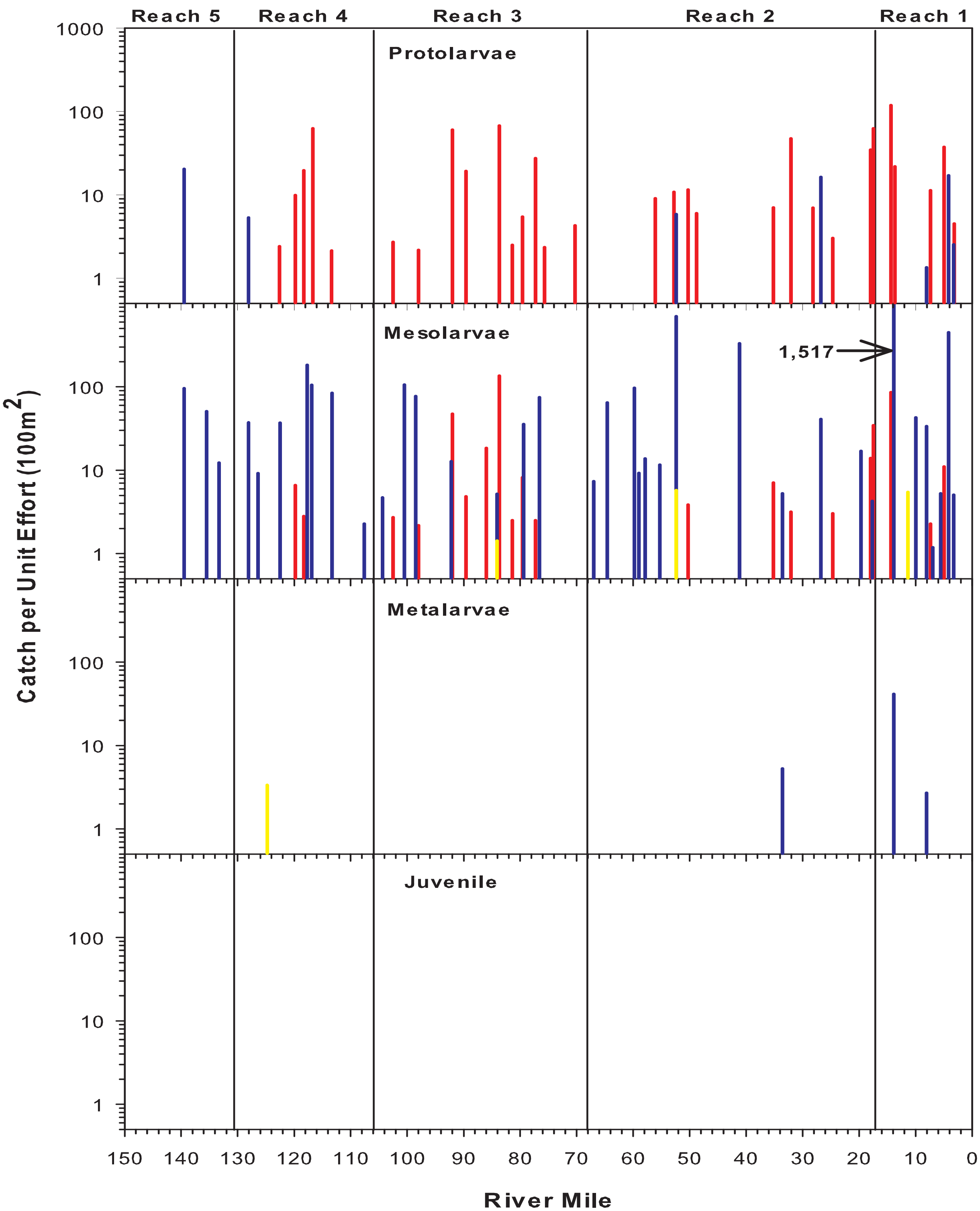


Figure 14. Catch per unit effort /100 m^2 of discrete ontogenetic stages (protolarvae, mesolarvae, metalarvae, and juvenile) of Razorback Sucker by sample locality during the 2015 survey. Red bars represent April collections, blue bars May collections and yellow bars June collections.

2015 Trip and Reach

Larval Razorback Sucker was first collected during the April survey, and was present in two subsequent sampling trips (Figure 8). Prior to 2015, 76 larval Razorback Sucker have been collected during April surveys in four different years (2002, 2006, 2007, and 2014). During the April 2015 survey, 305 larval Razorback Sucker were collected. Densities were highest during the May survey and this was the only month in which larvae were collected in each of the 5 reaches. During this trip, larval Razorback Sucker was found in 64.3% of all collections.

Densities of larval Razorback Sucker were highest in Reach 1 (32.1 fish per 100m^2) and lowest in Reach 5 [(2.3 fish per 100m^2) Figure 8]. The largest single collection of larval Razorback Sucker was in Reach 1 during the May Survey. During this month, 187 larvae were collected in a backwater habitat at river mile 13.9.

Common species

Bluehead Sucker. General linear models of Bluehead Sucker mixture-model estimates (Delta (δ) and Mu (µ)) revealed that the (δ(Reach) µ(Reach)) model received nearly all of the AIC_C weight (w_i) (Table 4). Bluehead Sucker was one of two species for which the (δ(Reach) µ(Reach)) model was ranked the highest. Among years, estimated densities ($E(x)$) were highest in 2013 (111.8) and lowest in 2009 [7.8 (Figure 15)]. Estimated densities in 2015 were significantly higher ($P < 0.05$) than 2003, 2008, and 2009 and not significantly lower than any preceding year. The 2,912 age-0 specimens collected accounted for 16.4% of the 2015 catch and Bluehead Sucker was found in 31.1% of all collections. Larval Bluehead Sucker was first collected during the April survey with the highest densities occurring during the May Survey (Figure 16). Within reaches, densities were highest in Reach 5 and lowest in Reach 1 (Figure 16).

Flannelmouth Sucker. Mixture-model estimates (Delta (δ) and Mu (µ)) for Flannelmouth Sucker showed that the (δ(Year) µ(Year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 5). Estimated densities ($E(x)$) were highest in 2008 (358.7) and lowest in 2013 [18.8 (Figure 17)]. Estimated densities in 2015 were significantly higher ($P < 0.05$) than most of the preceding years; the exceptions being 2007, 2008, 2011, and 2012 (Figure 17). Similar to Bluehead Sucker, age-0 Flannelmouth Sucker were first collected during the April survey, with densities peaking the following month (Figure 16). Densities were highest in Reaches 3 and 4, similar in Reaches 5 and 2, and lowest in Reach 1 (Figure 16). Larval Flannelmouth Sucker was the numerically dominant (n = 12,176) species in 2015 accounting for 68.5% of the total catch and was found in 55.3% of all collections.

Speckled Dace. General linear models of Speckled Dace mixture-model estimates (Delta (δ) and Mu (µ)) showed that the (δ(Reach) µ(Reach)) model received nearly all of the AIC_C weight (w_i) (Table 6). Speckled Dace and Bluehead Sucker were the two species for which the (δ(Reach) µ(Reach)) model was ranked the highest. Estimated densities ($E(x)$) for larval Speckled Dace were highest in 2004 (132.8) and lowest in 2003 [9.7 (Figure 18)]. In 2015 Speckled Dace estimated densities were significantly lower ($P < 0.05$) than any of the preceding years except 2003 and 2009 (Figure 18). Larval Speckled Dace were first collected during the May survey, and densities were highest during the mid-July survey (Figure 19). Densities of larval Speckled Dace were highest in Reach 5 and declined in each of the subsequent downstream reaches (Figure 19). Speckled Dace was found in 29.4% of all samples and made up 5.8% of the total catch.

Red Shiner. Mixture-model estimates (Delta (δ) and Mu (µ)) for Red Shiner revealed that the (δ(Year) µ(Year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 7). Estimated densities ($E(x)$) in 2015 were the lowest (1.6) of any year during the study period and is several orders of magnitude lower than the highest (3,725.1) estimated density of 2005 (Figure 20). Red Shiner estimated densities in 2015 were significantly lower ($P < 0.05$) than any previous year (Figure 20). Red Shiner larvae were first collected during the May survey, absent during the June survey, with the highest densities occurring during the two July surveys (Figure 19). Among reaches, densities were highest in Reach 4 and lowest in Reach 2. For the first time during the tenure of this study, age-0

Table 4. General linear models of Bluehead Sucker (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2015) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Reach) μ(Reach)	15	6,874.10	6,904.26	0.999
δ(.) μ(Reach)	11	7,101.64	7,123.72	<0.001
δ(Reach) μ(.)	7	7,119.49	7,133.52	<0.001
δ(Year) μ(Year)	39	7,099.11	7,178.14	<0.001
δ(.) μ(Year)	27	7,158.51	7,213.01	<0.001

[1] δ = probability of occurrence
[2] μ = mean of the lognormal distribution
[3] = Model variables included year, reach, and habitat type
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

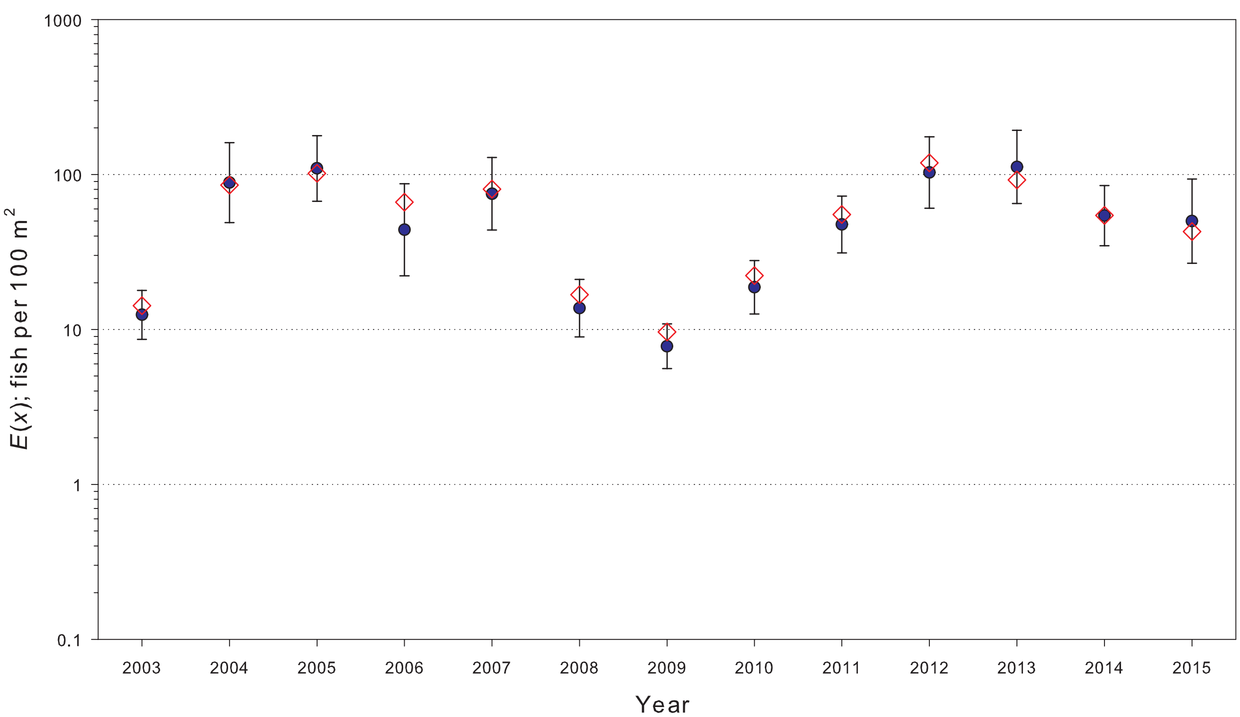


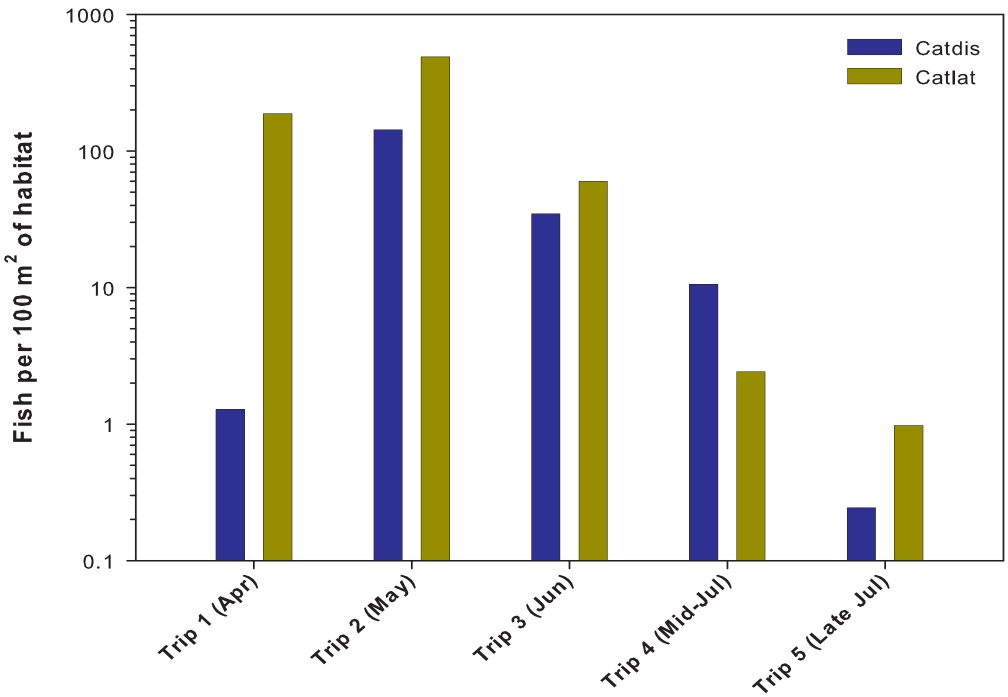
Figure 15. Bluehead Sucker (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Red Shiner were not collected in Reach 5 (Figure 19). Larval Red Shiner larvae accounted for 0.4% of the total 2015 catch and were found in 5.1% of the collections.

Fathead Minnow. Fathead Minnow mixture-model estimates (Delta (δ) and Mu (μ)) showed that the (δ(Year) μ(Year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 8). Estimated densities (*E*(*x*)) were highest in 2003 (168.8) and lowest in 2009 [0.7 (Figure 21)]. In 2015 estimated densities were significantly lower ($P < 0.05$) than most of the preceding years and only higher than 2009 (Figure 21). Larval Fathead Minnow were first encountered during the May survey, with densities being highest during the June survey (Figure 19). Among reaches, densities were lowest in Reach 5 but highest in the adjacent downstream Reach 4. Larval Fathead Minnow were the numerically dominant ($n = 236$) non-native species in 2015, yet comprised just 1.3% of the 2015 catch and was found in 16.7% of all collections.

Common Carp. Mixture-model estimates (Delta (δ) and Mu (μ)) for larval Common Carp revealed that the (δ(Year) μ(null)) model received nearly all of the AIC_C weight (w_i) (Table 9). This was the only common species in which the Mu (null) was part of the top model. Estimated densities (*E*(*x*)) were highest in 2004 (2.3) and lowest in 2010 [0.1 (Figure 22)]. Estimated density, with 95% confidence intervals, could not be computed for 2003 and 2006 since there was only a single non-zero value, which precluded mixture-model estimation of s. Estimated densities in 2015 were not significantly higher than any previous year but were lower ($P < 0.05$) than 2004 and 2005 (Figure 22). Larval Common Carp was first collected during the May survey, absent in June and mid-July, with a single individual collected in the late-July survey (Figure 23). Densities were highest in Reach 2 with no Common Carp collected in Reaches 5 or 3 (Figure 23).

Channel Catfish. Channel Catfish mixture-model estimates (Delta(δ) and Mu(μ)) revealed that the (δ(Year) μ(year)) model received nearly all of the AIC_C weight (w_i) despite having the most parameters (Table 10). Estimated densities (*E*(*x*)) were highest in 2007 (36.9) and lowest in 2015 [1.0 (Figure 24)]. Estimated densities in 2015 were significantly lower than any preceding year ($P < 0.05$) except 2009 (Figure 24). Larval Channel Catfish were first collected during the mid-July survey with densities being highest during that survey month (Figure 23). During the two July surveys when Channel Catfish were present, 43 individuals were collected in 21 of the 122 collections made during the July surveys. Channel Catfish densities were highest in Reach 1 with no Channel Catfish collected in Reach 4 (Figure 23).



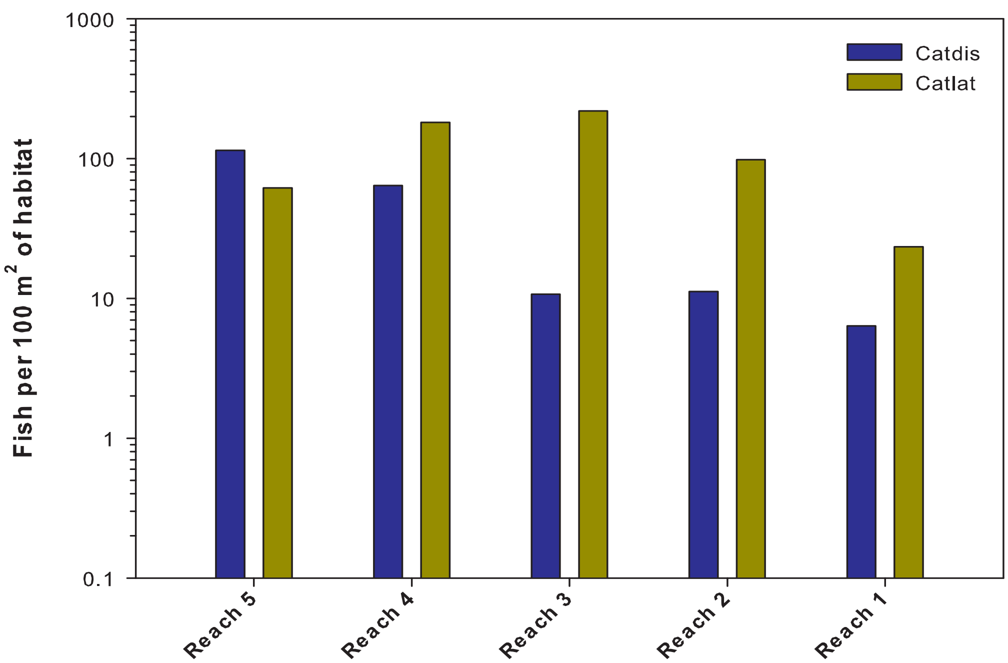


Figure 16. Density (fish per 100 m^2 of area sampled) of age-0 Bluehead Sucker (Catdis) and Flannelmouth Sucker (Catlat) by trip (top graph) and reach (bottom graph) during the 2015 survey.

Table 5. General linear models of Flannelmouth Sucker (age-0) mixture-model estimates (Delta (δ) and Mu (μ)), using sampling-site density data (2003–2015) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[1]	K[2]	logLike[3]	AIC_C	w_i
δ(Year) μ(Year)	39	7,824.38	7,903.38	0.999
δ(.) μ(Year)	27	7,913.95	7,968.43	<0.001
δ(Reach) μ(Reach)	15	7,941.04	7,971.19	<0.001
δ(Habitat) μ(Habitat)	18	7,957.11	7,993.32	<0.001
δ(Year) μ(.)	15	7,976.45	8006.60	<0.001

[1] = Model variables included year, reach, and habitat type
[2] = Number of parameters in the model
[3] = -2[log-likelihood] of the model
[4]δ = probability of occurrence
[5]μ = mean of the lognormal distribution

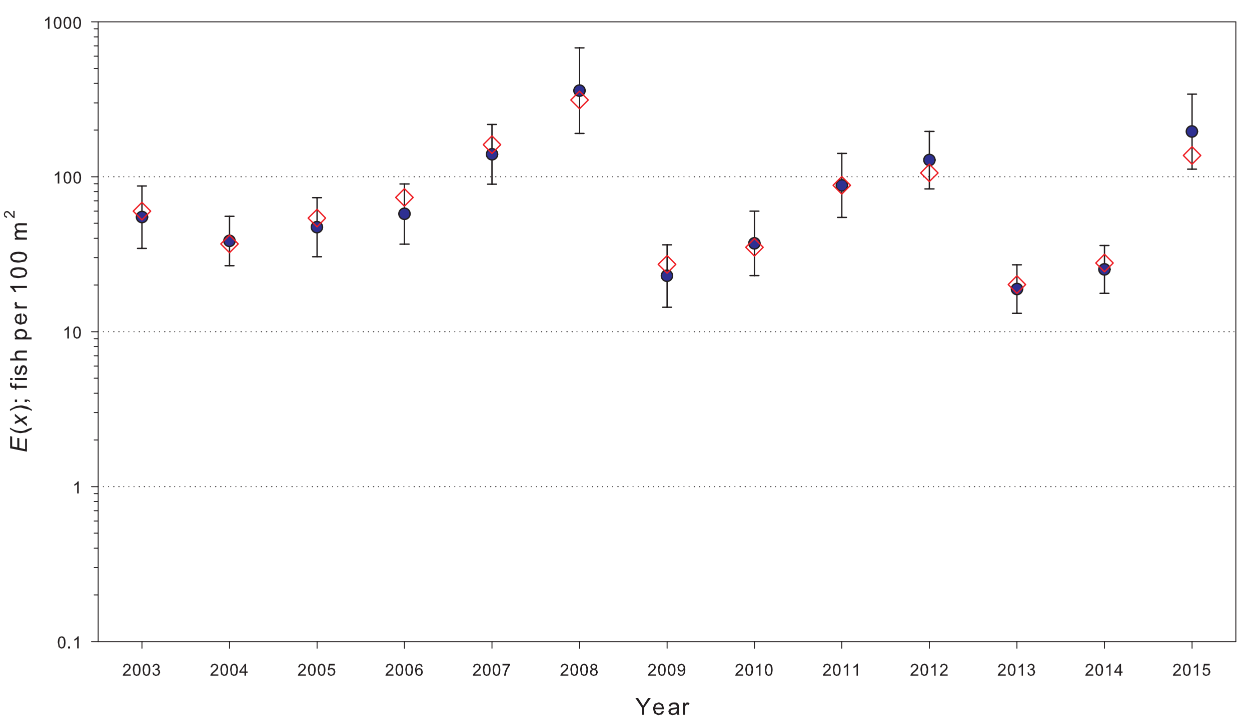


Figure 17. Flannelmouth Sucker (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 6. General linear models of Speckled Dace (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2015) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Reach) μ(Reach)	15	7,053.55	7,083.70	0.999
δ(Year) μ(Year)	39	7,127.69	7,206.73	<0.001
δ(.) μ(Reach)	11	7,210.95	7,233.04	<0.001
δ(Reach) μ(.)	7	7,229.14	7,243.17	<0.001
δ(.) μ(Year)	27	7,227.21	7,281.71	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach, and habitat type
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

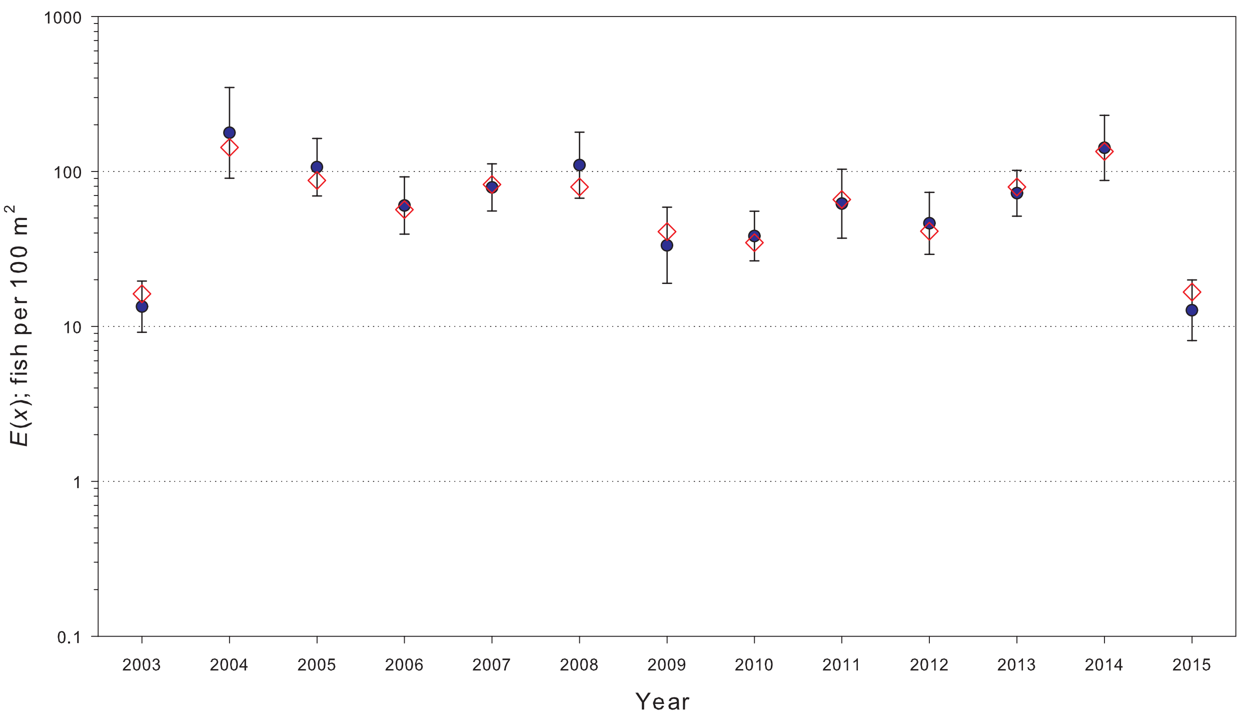


Figure 18. Speckled Dace (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

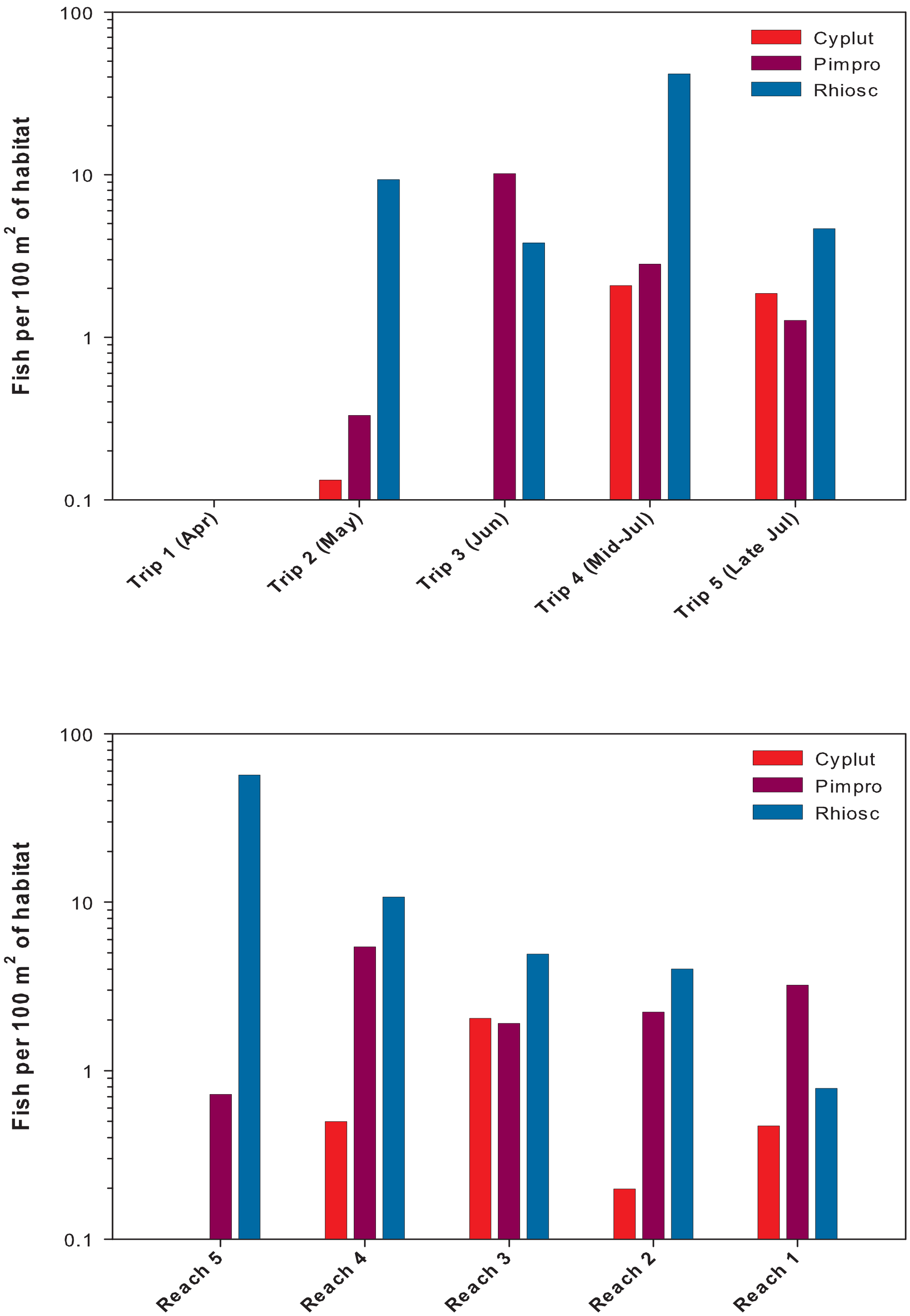


Figure 19. Density (fish per 100 m^2 of area sampled) of age-0 small-bodied cyprinids: Red Shiner (Cyplut), Fathead Minnow (Pimpro) and Speckled Dace (Rhiosc) by trip (top graph) and reach (bottom graph) during the 2015 survey.

Table 7. General linear models of Red Shiner (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2015) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	39	3,849.25	3,929.32	0.999
δ(Year) μ(.)	15	4,166.11	4,196.43	<0.001
δ(.) μ(Year)	27	4,265.56	4,320.55	<0.001
δ(Habitat) μ(Habitat)	18	4,425.03	4,461.48	<0.001
δ(.) μ(Habitat)	13	4,485.92	4,512.16	<0.001

[1] δ = probability of occurrence
[2] μ = mean of the lognormal distribution
[3] = Model variables included year, reach and habitat type
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

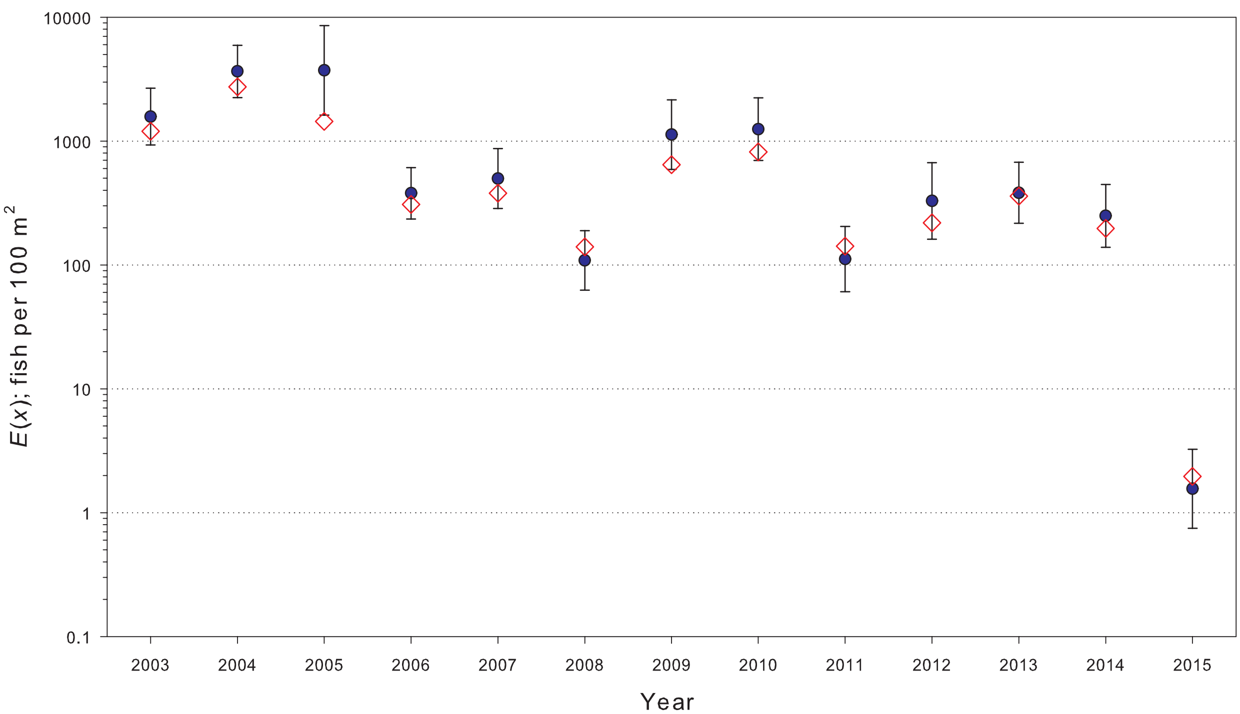


Figure 20. Red Shiner (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 8. General linear models of Fathead Minnow (age-0) mixture-model estimates (Delta (δ)[1] and Mu(m)[2]), using sampling-site density data (2003–2015) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	39	5,816.71	5,895.74	0.999
δ(Year) μ(.)	15	6,014.91	6,045.06	<0.001
δ(Reach) μ(Reach)	15	6,044.97	6,075.12	<0.001
δ(.) μ(Year)	27	6,084.42	6,138.92	<0.001
δ(Reach) μ(.)	7	6,136.54	6,150.58	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach and habitat type
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

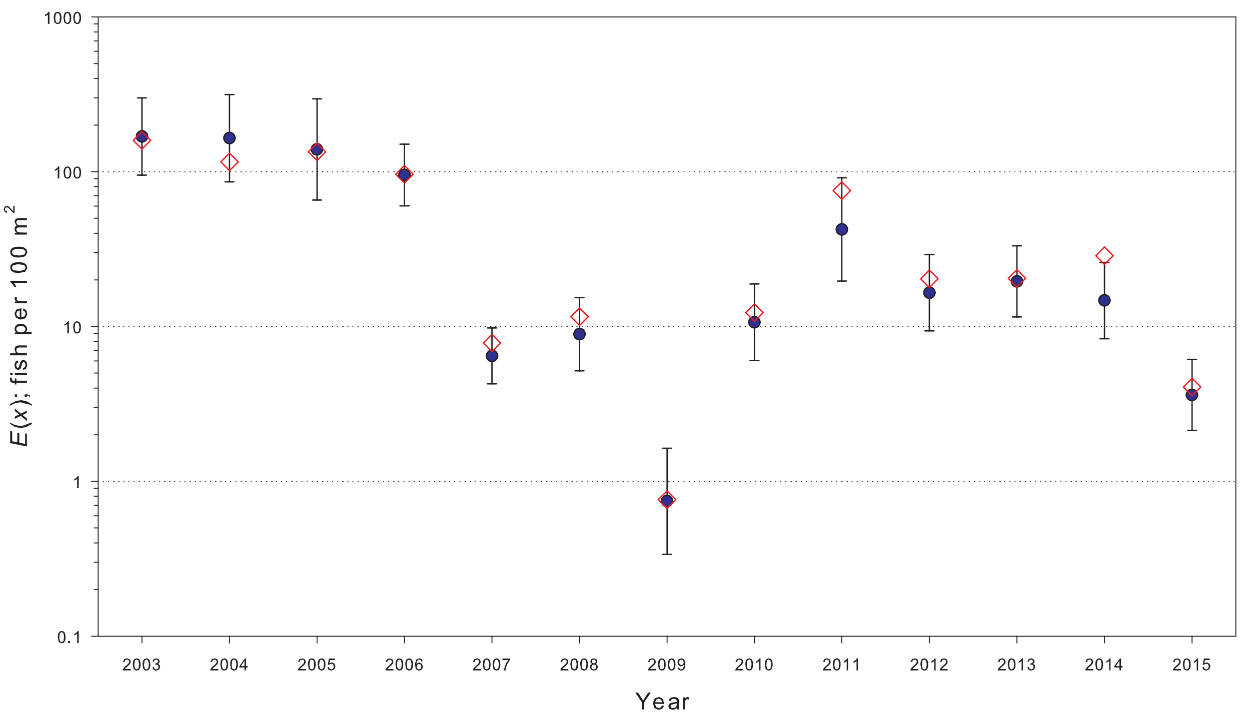


Figure 21. Fathead Minnow (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

Table 9. General linear models of Common Carp (age-0) mixture-model estimates (Delta (δ)[1] and Mu (μ)[2]), using sampling-site density data (2003–2015) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(.)	15	1,629.36	1,659.52	0.999
δ(Year) μ(Year)	39	1,600.57	1,679.61	<0.001
δ(Reach) μ(Reach)	15	1,701.58	1,731.73	<0.001
δ(Habitat) μ(Habitat)	18	1,701.63	1,737.86	<0.001
δ(Habitat) μ(.)	8	1,724.73	1,740.77	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach and habitat type
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

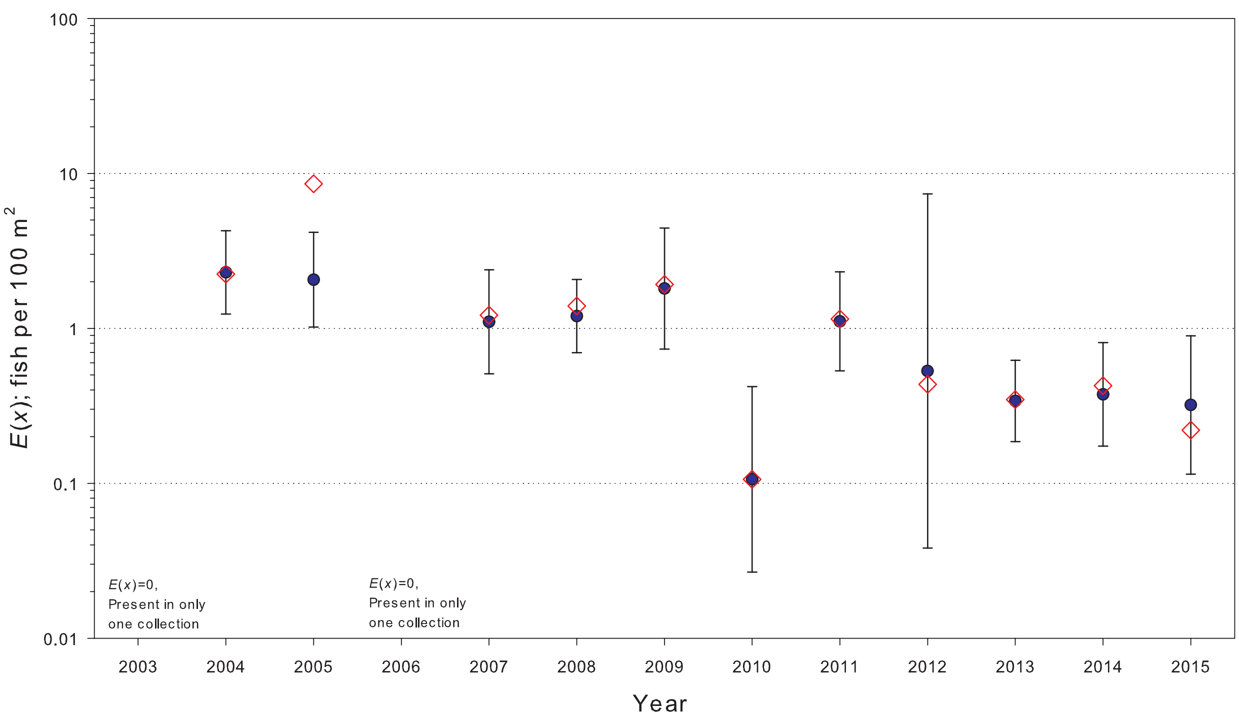
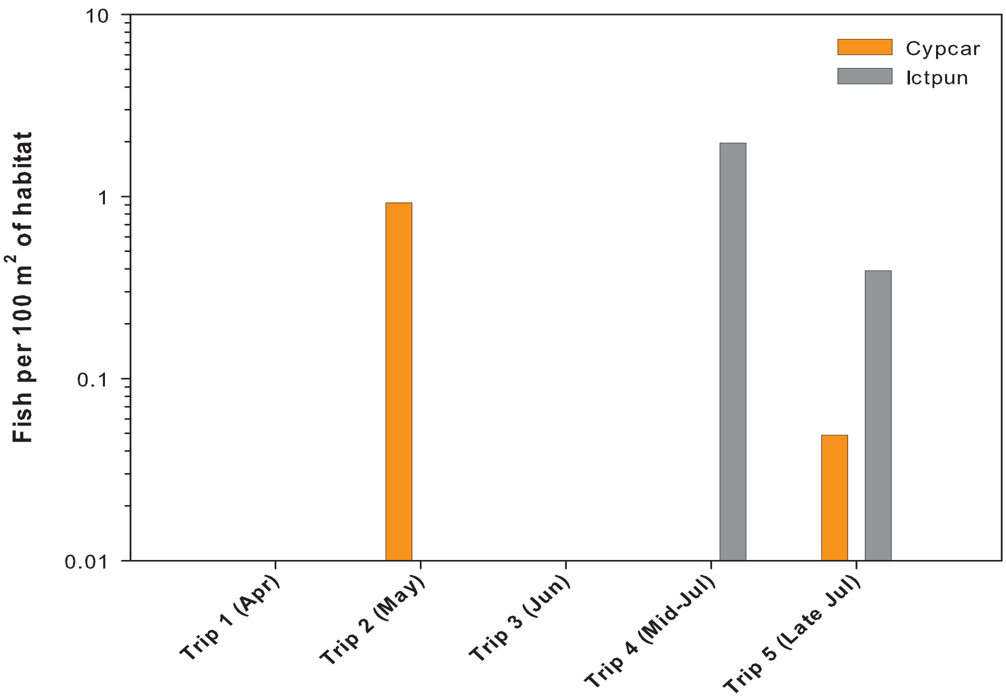


Figure 22. Common Carp (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.



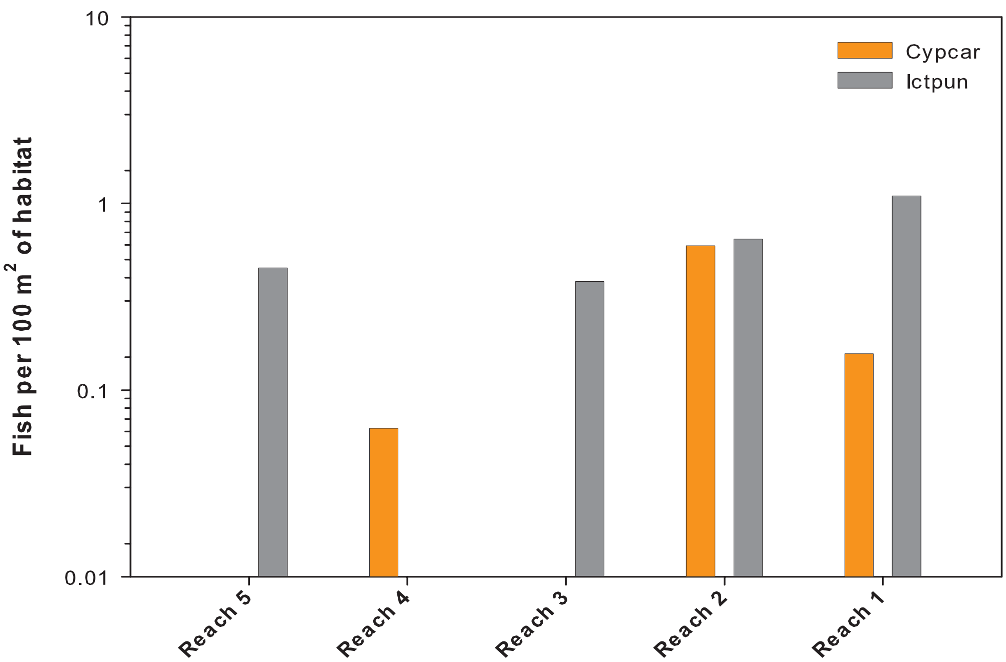


Figure 23. Density (fish per 100 m^2 of area sampled) of age-0 Common Carp (Cypcar) and Channel Catfish (Ictpun) by trip (top graph) and reach (bottom graph) during the 2015 survey.

Table 10. General linear models of Channel Catfish (age-0) mixture-model estimates (Delta (δ)[1] and Mu (m)[2]), using sampling-site density data (2003–2015) and spatial covariates. Models are ranked by Akaike's information criterion (AIC_C) and include the AIC_C weight (w_i).

Model[3]	K[4]	logLike[5]	AIC_C	w_i
δ(Year) μ(Year)	39	2,722.32	2,802.39	0.999
δ(Year) μ(.)	15	2,833.09	2,863.41	<0.001
δ(Reach) μ(Reach)	15	2,866.97	2,897.29	<0.001
δ(Reach) μ(.)	7	2,907.73	2,921.80	<0.001
δ(.) μ(Year)	27	2,925.10	2,980.10	<0.001

[1]δ = probability of occurrence
[2]μ = mean of the lognormal distribution
[3] = Model variables included year, reach and habitat type
[4] = Number of parameters in the model
[5] = -2[log-likelihood] of the model

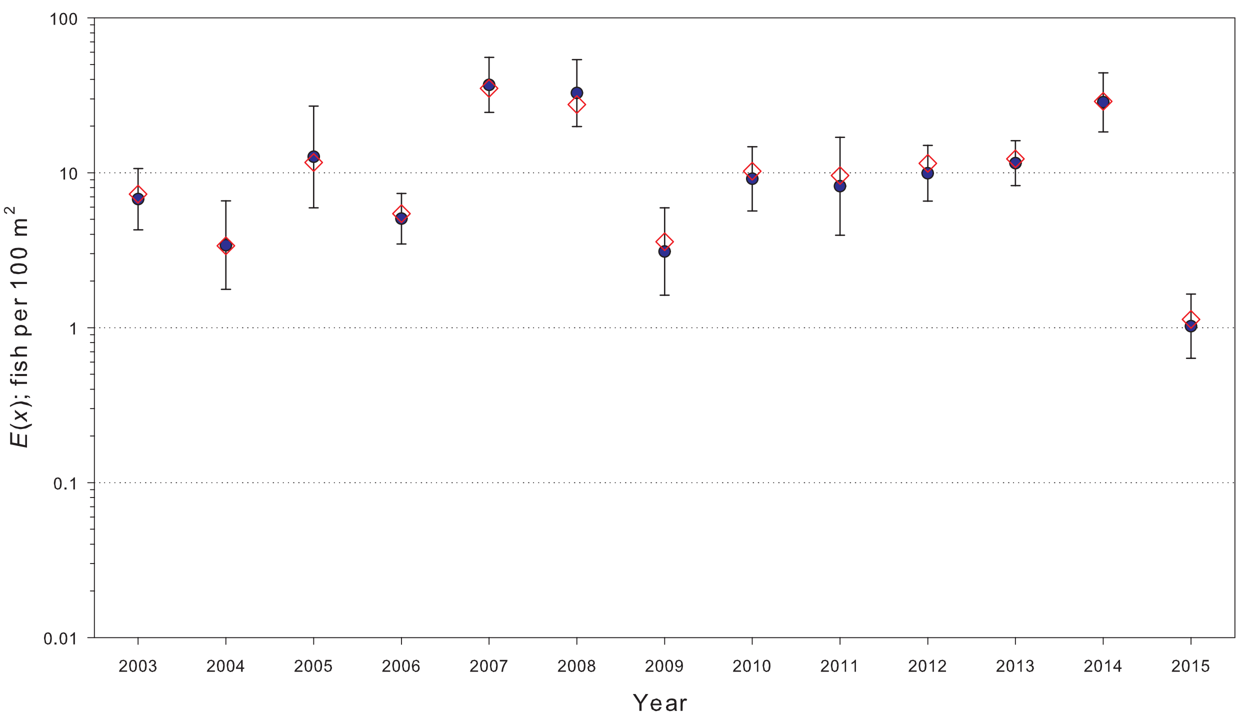


Figure 24. Channel Catfish (age-0) mixture-model estimates ($E(x)$) using sampling-site density data (2003–2015). Solid circles indicate estimates and bars represent 95% confidence intervals. Red diamonds indicate simple estimates of mean densities using the method of moments.

2015 Razorback Sucker opercular deformities.

In 2015, age-0 Razorback Sucker were rated for opercular deformities using the methods outlined in a previous investigation of opercular deformities in native suckers from 1998–2012 (Barkstedt et al. 2014). The opercular deformity study completed in 2013 rated all three native suckers from collections in 1998–2012 (*n* = 55,385). Between 1998 and 2012, opercular deformities were found in 4.3% of Bluehead Sucker (*n* = 8,565), 6.3% of Flannelmouth Sucker (*n* = 45,416), and 23.6% of Razorback Sucker (*n* = 1,404). In 2015 Razorback Sucker individuals (>15 mm TL) were rated bilaterally for deformed opercula on a scale of 0 (none), 1 (slight shortening), and 2 [severe shortening (Figure 25)].

A total of 347 specimens were rated with 65 (18.7%) exhibiting deformed opercula (Figure 26). Of the 347 fish rated all were meso- or metalarvae as there were no juvenile Razorback Sucker collected in 2015. Fish were rated from each of the geomorphic reaches within the study area, with deformed fish found in each reach. Deformities were found bilaterally (6.6%, *n* = 23) and unilaterally (12.1%, *n* = 42). Severe deformities (a rating of 2) were found in 13 fish, with about half (*n* = 6) having bilateral deformities. The deformity rate in 2015 (18.7%) was lower than that documented in 2014 (34.1%).

Figure 25. Age-0 Flannelmouth Suckers from the San Juan River displaying opercular deformities. The top two fish would be rated as severely deformed (“2”), and the bottom fish would be rated as slight shortening (“1”).

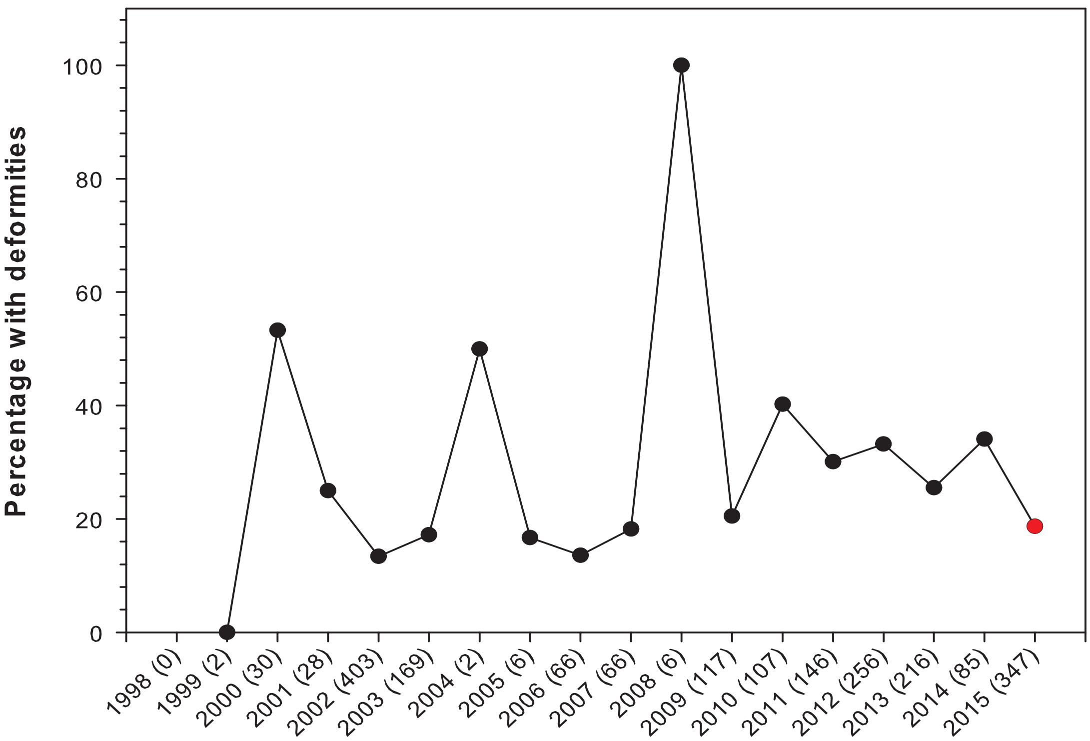


Figure 26. Percentage of Razorback Sucker with opercular deformities by year. The number of fish examined is reported in parentheses.

Monitoring sites

During the 2015 survey, a total of 74 visitations were made to the 15 monitoring sites within the study area (Table A-3). Typically 75 visitations are reported (15 sites x five trips) each year, however the monitoring site at river mile 96.4 (Allen Canyon) was missed during the June survey. Each site was sampled if suitable nursery habitat was available, otherwise photographs were taken and conditions noted on a field data sheet. During 74 visitations to the monitoring sites, backwater habitats were encountered 32 times, isolated pools were found 10 times, with 28 visitations being to dry sites. On five occasions recent rain events resulted in flow through the monitoring sites. During these five visitations, habitat types encountered included pools (n = 2), sand shoals (n = 2) and, in one instance, a run type habitat.

The highest level of connectivity observed during 2015 was during the June survey with the lowest occurring during the late-July survey (Figure 27). During 2015, 36 collections encompassing 1268.2 m^2 of habitat were made at monitoring sites. These collections contained 2,550 age-0 fish including 226 larval Razorback Sucker. This represents 18.8% of the 2015 Razorback Sucker total. There was no larval Colorado Pikeminnow collected within the monitoring sites in 2015. Three age-1 Colorado Pikeminnow were collected at two monitoring sites during the May survey.

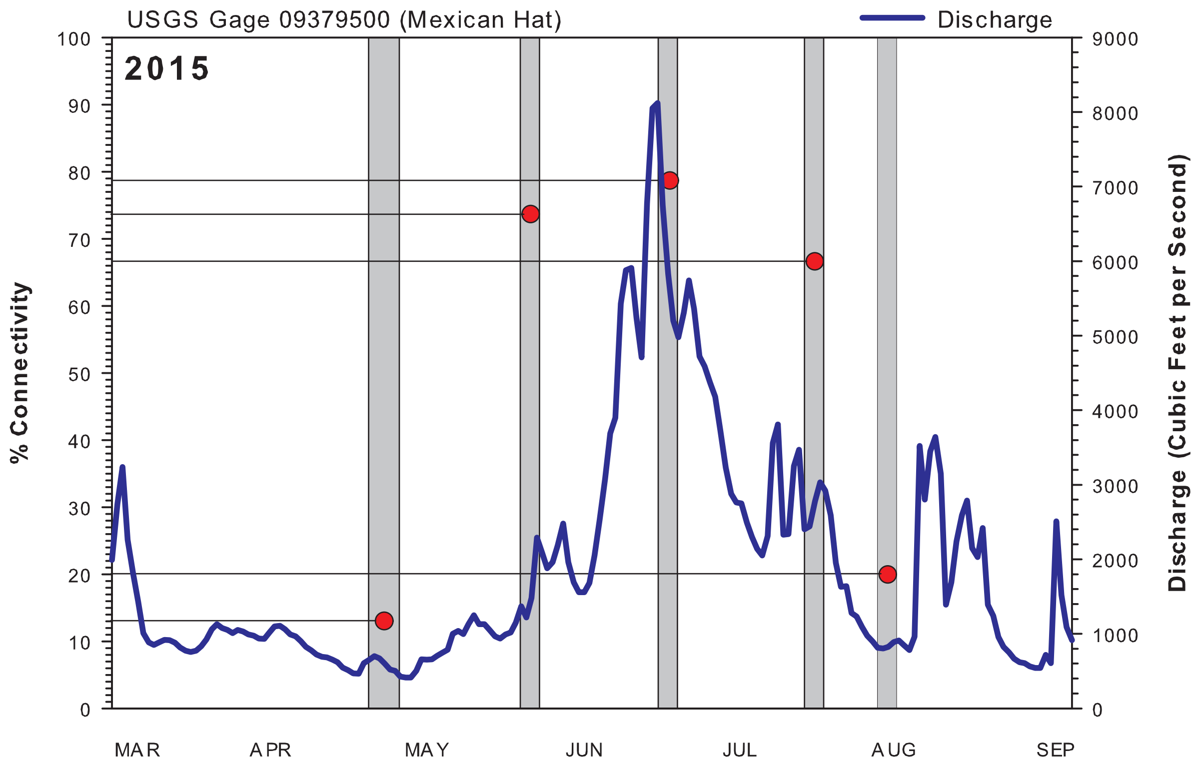


Figure 27. Mean connectivity of the 15 monitoring sites during the five survey trips denoted by gray bars.

RERI sites

During the 29 RERI site visitations (typically 30 visitations but one site was missed in April), 11 collections yielded eight species and a total of 462 age-0 specimens (Table 11). Two of the RERI sites contained age-0 Razorback Sucker. Twenty Razorback Sucker were captured in May and at the river miles 128.6 (*n* = 16) and 127.2 (*n* = 4) sites. There was no Colorado Pikeminnow of any age class collected at an RERI site in 2015.

An effort was made to compare the six RERI sites to other, similar sites sampled in 2015. Capture data were separated for all sites located within the same five river miles as the RERI sites, and for all sites within five miles up or downstream of the RERI sites (RM 137.2–122.2). Within this pool of sites, all habitats associated with washes, arroyos, or tributaries were excluded from analysis. The remaining sites (*n* = 18) were all habitats that were directly associated with either the main or a secondary channel. Similar to the 11 collections made within the RERI sites, not all of these 18 sites contained fish at the time of visitation. These 18 sites are considered the "control" sites.

Age-0 species composition was similar between the RERI and control sites. The native species composition was the same for the RERI and control sites, and each group of sites contained Fathead Minnow, Western Mosquitofish, and Largemouth Bass. Channel Catfish was the single non-native species found within the RERI sites that was not in the control sites. Conversely, the controls sites contained Red Shiner, which was not found in the RERI sites. The proportion of native to non-native species found between the RERI and control sites was also similar. Of the 462 specimens collected in the RERI sites, 98.9% were native species. Control sites yielded 1,079 specimens, with 97.7% of those fish being native species.

Table 11. Species composition and habitat type of the six RERI sites sampled in 2015. Six letter species codes are defined in Table A-6.

RERI (RM)	Survey Month	Water Descriptor	Q (CFS)		PTYLUC	RHIOSC	CATDIS	CATLAT	XYRTEX	CYPLUT	PIMPRO	MISC. Sp.
136.7 - 134.5	April	Backwater	522									
	May	Run, not sampled	1,370									
	June	Run, not sampled	5,200									
	Mid-July	Run, not sampled	2,780									
	Late July	Pool	825								1	1 Micsal
				Total							**1**	**1**
132.2	April	Sand shoal	522									
	May	Site dry	1,370									
	June	Run, not sampled	5,200									
	Mid-July	Sand shoal	2,780			28	3	1				1 Ictpun
	Late July	Site dry	825									
				Total		**28**	**3**	**1**				**1**
132	April	Site missed	522									
	May	Site dry	1,370									
	June	Run, not sampled	5,200									
	Mid-July	Run, not sampled	2,780									
	Late July	Sand shoal	825			1						
				Total		**1**						
130.7 A	April	Site dry	522									
	May	Sand shoal	1,370				25	146				
	June	Run, not sampled	5,200									
	Mid-July	Run, not sampled	2,780									
	Late July	Pool	825			2						
				Total		**2**	**25**	**146**				
130.7 B	April	Run, not sampled	522									
	May	Run, not sampled	1,370									
	June	Run, not sampled	5,200									
	Mid-July	Run, not sampled	2,780									
	Late July	Run, not sampled	825									
				Total								
128.6	April	Site dry	522									
	May	Backwater	1,370			4	33	130	16			
	June	Run, not sampled	5,200									
	Mid-July	Run, not sampled	2,780									
	Late July	Pool	825			4						2 Gamaff
				Total		**8**	**33**	**130**	**16**			**2**
127.2	April	Site dry	522									
	May	Sand shoal	1,370			2	5	53	4			
	June	Run, not sampled	5,200									
	Mid-July	Run, not sampled	2,780									
	Late July	Sand shoal	825									
				Total		**2**	**5**	**53**	**4**			

DISCUSSION

For the third consecutive year, general linear models that included multiple covariates were used to elucidate changes in the occurrence and density of endangered species over time. Environmental covariates included in the 2015 models included mean discharge and temperature during the back-calculated spawning period for both Colorado Pikeminnow and Razorback Sucker. Fall monitoring capture data (for Razorback Sucker and Colorado Pikeminnow) and augmentation data (for Razorback Sucker only) was also included. Categorical covariates included year, reach and habitat type.

The top model for age-0 Colorado Pikeminnow had the year covariate for delta(δ) and null for mu(m). This is different than the 2014 results, which incorporated fall monitoring covariates for mu(m) in the two top models. In 2014 fall monitoring captures were divided into two size-classes; fish > 450 mm TL and fish that were 300–449 mm TL. It was assumed that fish > 450 mm TL were fully capable of spawning, and that fish in the 300–449 mm TL range had some potential to spawn. In 2015, fall monitoring capture data was condensed into a single category of fish > 400 mm TL. This was done based on the assumption that fish would spend 8-10 months in the river between the time of capture in the fall and the subsequent onset of summer spawning. During this time, these fish would presumably grow and recruit into the adult population and be capable of spawning. This new fall monitoring covariate was incorporated into both delta(δ) and mu(m) as the eleventh ranked model, but received little AIC_C weight (>0.001). While a direct comparison between the 2014 monitoring covariates and the 2015 monitoring covariate is not possible, an analysis of deviance between the two years may provide some insight as to why fall monitoring captures was not incorporated into a top model in 2015. In 2014, the fall monitoring > 450 mm TL covariate accounted for 21.9% of the deviance explained by the μ(Year) over the null μ(.) model. In 2015, the new fall monitoring covariate of > 400 mm TL was outperformed by the null μ(.) model, and did not account for any of the deviance explained by the μ(Year) over the null μ(.) model.

The collection of 24 flexion mesolarval Colorado Pikeminnow during the final late-July survey suggests that spawning by adult Colorado Pikeminnow occurred later than is typical. The back-calculated spawning period of 10–14 July is one of the latest recorded during the tenure of this study. Prior to 2015, back-calculated spawning dates were generated for 358 Colorado Pikeminnow larvae; only 7 of those individuals had July back-calculated spawning dates. The remainder all had June back-calculated spawning dates. The capture of a metalarval specimen during the fall small-bodied monitoring also is suggestive of a later than usual spawning period. That individual had a back-calculated spawning date of 19 August 2015 (pers. comm. M. Zeigler, NMGF). There is no obvious environmental factor that might explain delayed spawning by Colorado Pikeminnow. Typical cues such as the descending limb of the spring hydrograph and mean river temperatures above 20^{o}C occurred nearly a month earlier than the 10–14 July back-calculated time frame.

For the eighteenth consecutive year, spawning by adult Razorback Sucker was documented in the San Juan River. Larvae were documented during three of the five surveys and found throughout the entire study area suggesting that an established adult population resides within the San Juan River. Mixture-model estimates using sampling-site data showed that the (δ(Year) μ(year)) model received most (.50) of the AIC_C weight. The second top model incorporated May discharge in the mu model parameter and received nearly as much (0.47) of the AIC_C weight. The top model ranking in 2015 is different than that of 2014. In 2014, the top model incorporated the cumulative stocking covariate for both delta and mu and received 0.72 of the AIC_C weight. Model results are similar for the second ranked model between 2014 and 2015 in that both included the May flow covariate. Estimated densities for Razorback Sucker were the highest ever recorded in 2015, although this year is statistically similar to 2002, and 2010–2014.

Larval Razorback Sucker from the 100,000 fish released during the Hogback diversion study were collected in the 2015 samples. Otoliths from 226 larvae were examined for an OTC mark. Six individuals were found to have an OTC mark; this equates to a recapture rate of 2.7%. There were five larval Razorback Sucker collected during the June survey and none were found to have an OTC mark. The release of larvae into the Hogback canal occurred weeks after the April survey so it is known that the 305 fish collected during that month were wild spawned fish.

The six individuals that were marked came from three discrete localities and were collected during the May survey. Given that 895 larval Razorback Sucker were collected during the May survey, the theoretical number of fish that would have come from the Hogback stocking is 24 individuals (2.7% x 895). The decision was made not to remove these larvae from the database prior to the mixture-model runs. Three key factors drove this decision. First, all collections that contained a single larval Razorback Sucker were examined for the presence of an OTC mark. The collection of a single larva particularly influences the estimation of delta (i.e. presence or absence) within the models. None of these fish were found to have an OTC mark. Second, the larvae that were found to have an OTC mark had demonstrated an ability to survive within the San Juan River for weeks after being stocked into the Hogback canal. One could argue that their potential contribution to the Razorback Sucker population within the San Juan River was just as valuable as a wild spawned individual. Third, it was believed that the relatively low recapture rate, and subsequent low number of theoretically OTC marked fish, would have done little to influence the overall model results.

For both Colorado Pikeminnow and Razorback Sucker, habitat data that incorporate specific spatial components such as location of individual (i.e. seine haul) sampling efforts have only been available since 2013. For both species estimated densities were highest in backwater habitat types. These results were similar to previously reported habitat analysis done for Razorback Sucker (Farrington et al., 2013) with 2014 and 2015 being the only two years this type of analysis was done for Colorado Pikeminnow. Within backwaters and embayments, the terminal portion of the habitat had the highest estimated densities of Colorado Pikeminnow. In an effort to keep density data unbiased among the different locations (mouth, shoreline, open water and terminus) within these habitat types, there was no set order in which the locations were sampled. It could be argued that if the first sample were to occur at the mouth, and the last to occur at the terminal end, that the sampling activities of the researchers may "herd" larvae towards the terminal end resulting in higher densities within these locations. To avoid this, the order of sampling for each of the locations was kept random. The continued collection of detailed habitat information and the compilation of a long term data set should further elucidate habitat and fish use relationships.

Mixture-model estimates were also done for several of the common species in 2015. Covariates used in these models were year, reach and habitat type. For many species, the model runs in 2015 indicated that most of the variation in density was explained by the year model (δ(Year) m(Year)). The two exceptions to this were Speckled Dace and Bluehead Sucker. For both of these species the (δ(Reach) m(Reach)) model received most of the AIC_C weight (w_i). Densities for these species are highest in upstream reaches of the study area and decrease in the downstream reaches.

Estimated densities in 2015 for many of the common species were lower than those of 2014. For some species, the estimated densities were among the lowest recorded during the tenure of this study. In general, species that typically spawn during the late-spring or summer months saw the biggest declines in 2015. The combined total of age-0 fish collected during the two July surveys was the lowest every recorded; the late-July survey produced just 217 fish. Typically, about 38,000 age-0 fish are collected during the final two surveys, with just 1,310 being collected in 2015. The reason for this apparent decline is unknown. Discharge and temperature regimes were similar to prior survey years (particularly 2006 and 2011) that did not see the same decline in the number of larvae collected.

While opercular deformities continue to be observed in young-of-year Razorback Sucker, the percentage of affected larvae in 2015 was among the lowest recorded and the yearly (1998–2015) trend data does not suggest an increase, or decrease, in the overall deformity rate. It is worth noting that the highest recorded occurrences of opercular deformities have been in years in which the overall sample size was small. The only three years in which the deformity rate was 50% or higher were 2000, 2004, and 2008; the sample size for those years was 30, 2, and 6 fish respectively. Years with a much higher numbers of individuals examined (e.g. 2015) are likely more representative of the overall deformity rate.

The monitoring sites established for this study continue to illustrate the dynamic nature of habitats in the San Juan River. As was noted in the 2014 larval fish survey report, there is no clear pattern in site inundation and river stage. Examination of the five-year (2011–2015) database revealed that the mean connectivity of the 15 monitoring sites has been 39.8%. Among the sites, the lateral wash located at river mile 119.5 has had the lowest level (20.0%) of connectivity. This site has been inundated at flows as low as 790 cfs, and disconnected from the river at flows as high as 5,200 cfs. Conversely, the wash located at river mile 116.9 (Cowboy Wash) has had the highest level of connectivity (62.5%). This site has consistently been connected to the river at flows above 950 cfs.

What has remained consistent over time is the productivity of these sites when they are connected to the river. During 2015, when sampled, monitoring sites contained larval fish 80.0% of the time. Most of the samples that did not produce fish were from the two July surveys. Throughout the study area, both of the July surveys produced an unusually low number of larval specimens. During 2015, 14.3% of the total area sampled was within the monitoring sites, yet 18.8% of all Razorback Sucker larvae were collected in these sites.

During 2015, habitat types encountered in the six phase I RERI sites included backwaters, pools, sand shoals, and runs. During previous survey years, the primary reason for a larval fish collection not being made in these restoration sites was the fact that the site was dry. During 2015, dry sites were only encountered in six of the 29 visitations. Rather, it was the presence of run type habitats and the lack of suitable nursery habitats in 2015 that resulted in just 11 collections being made. Regardless of the number of collections made, the 2015 survey results once again show that these restored secondary channels provide nursery habitat, are used by endangered species, and contain the same proportions of native and non-native species as other habitats within the San Juan River. Because there is a specific monitoring effort in place for the Phase II RERI restoration site located between river miles 136.7 and 134.5, this site is not the focus of intensive monitoring during the larval fish surveys. Whenever possible, opportunistic collections have been made within the Phase II site and that information freely shared with the principle investigators responsible for the Phase II monitoring.

The difference in covariates between 2014 and 2015 that were incorporated into the top models for both Colorado Pikeminnow and Razorback Sucker was unexpected. For Colorado Pikeminnow a partial explanation seem to that the fall monitoring covariates used in the 2014 were changed and condensed into a single fall monitoring covariate. The covariates used in the 2015 models will remain unchanged for the 2016 models. It is important to note that while the use of covariates is important in trying to understand some of the underlying processes that drive differences in occurrence and density, they in no way affect any of the model estimations. Mixture-models remain a valuable tool for monitoring the status of endangered species within the San Juan River

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APPENDIX A

Figure A-1. Example of field data recorded at each sampling locality.

Field No.: MAF15-110

Date: 14 July 2015 Acc. No.: 2015-IV.20

State/Country: Utah Locality: San Juan River @ RM 38.8

County: San Juan Drainage: San Juan Quad.: The Goosenecks

Coordinate System: UTM Datum: NAD 27 Zone: 12S

Start: E/W: 593242 N/S: 4113708 Stop: E/W: N/S:

Shore Description: Willow Air Temp.: 25 °C

Water Description: Sand shoal

Substrate: Sand Water Depth: <0.14 m

Aquatic Vegetation / Cover: none /

Water Temp.: 23.1 °C Velocity (est.): 0.01-0.10 m/s Width (est.): <4.0 m Secchi Depth: 1 cm

D.O.: 6.87 mg/l Conductivity (µS): C 467 / Sc 485 Salinity: 0.23 ppt pH: 7.62

Method of Capture: larval seine /

No. Hauls: 4 Area: 25.6 m² Shocking Sec.: Volts: Amps:

Collectors: MA Farrington SL Durst

Time: (start) 0932 h (stop) 0945 h Notes taken by: MAF

Orig. Preservative: N/A Photographs: 0743

Released fishes: Yes / No (list separately): N=1 Pty luc mmSL/TL 145/184 Larval fishes: Yes / No

Haul #1 PIT tagged the fish.
3D91BF18D13EØ

1) SS SH - 9.0m

2) SS SH - 6.3m

3) SS SH - 6.8m

4) SS SH - 3.5m

Table A-1. Summary of larval Colorado Pikeminnow in the San Juan River (1993-2015) and back-calculated dates of spawning.

Year	Number of Specimens	Spawning dates	Distribution (river miles)	Sample Method
1993	2	8-9 July	53.0	drift netting
1995	2	15-17 July	53.0	drift netting
1996	1	18 July	127.5	drift netting
2001	1	17 July	127.5	drift netting
2004	2	24-25 June	17.0 - 46.3	larval seine
2007	3	27 June	33.7 - 107.7	larval seine
2009	1	10 June	24.7	larval seine
2010	5	15-27 June	13.0 - 58.9	larval seine
2011	29	23 June -12 July	7.0 - 92.6	larval seine
2013	12	23 May - 3 July	10.0 - 107.6	larval seine
2014	312	15 June - 2 July	3.2 - 116.9	larval seine
2015	24	10 July – 14 July	57.2 – 94.8	larval seine
Total	**394**			

Table A-2. Summary of larval and age-0 Razorback Sucker collected during the San Juan River larval fish survey 1998-2015.

Year	Study Area	Project Dates	Total Effort m^2	Xyrtex	Sample Method
1998	127.5 - 53.0	17 Apr - 6 Jun	-	2	larval seine/ light trap
1999	127.5 - 2.9	5 Apr - 10 Jun	2,713.5	7	larval seine/ light trap
2000	127.5 - 2.9	4 Apr - 23 Jun	2,924.6	129	larval seine/ light trap
2001	141.5 - 2.9	10 Apr - 14 Jun	5,733.1	50	larval seine/ light trap
2002	141.5 - 2.9	15 Apr - 12 Sep	9,647.5	815	larval seine/ light trap
2003	141.5 - 2.9	15 Apr - 19 Sep	13,564.6	472	larval seine
2004	141.5 - 2.9	19 Apr - 14 Sep	11,820.3	41	larval seine
2005	141.5 - 2.9	19 Apr - 14 Sep	10,368.6	19	larval seine
2006	141.5 - 2.9	17 Apr - 15 Sep	12,582.6	202	larval seine
2007	141.5 - 2.9	16 Apr - 19 Sep	13,436.0	200	larval seine
2008	141.5 - 2.9	14 Apr - 13 Sep	14,292.3	126	larval seine
2009	141.5 - 2.9	13 Apr - 26 Sep	15,860.3	272	larval seine
2010	141.5 - 2.9	19 Apr - 3 Sep	16,761.0	1,251	larval seine
2011	141.5 - 2.9	13 Apr - 26 Sep	9,387.9	1,065	larval seine
2012	147.9 - 2.9	16 Apr - 9 Aug	8,269.8	1,778	larval seine
2013	147.9 - 2.9	21 Apr - 2 Aug	9,750.0	979	larval seine
2014	147.9 - 2.9	21 Apr - 31 July	8,623.0	612	larval seine
2015	147.9 - 2.9	19 Apr - 30 July	8,886.4	1,205*	larval seine
TOTAL				**9,225**	

* The 2015 total includes larval fish recaptured from a stocking at the Hogback Diversion (RM 158.8)

Table A-3. Locality and description of the 15 monitoring sites designated for habitat persistence.

River Mile	Reach	Easting	Northing	Locality description	
124.8	4	678281	4091267	lateral wash	river left
119.5	4	675632	4096476	lateral wash	river left
118.5	4	674456	4097745	lateral wash	river left
116.9	4	673442	4100108	lateral wash	Cowboy Wash
104.4	3	663008	4115111	lateral wash	river left
96.4	3	654559	4123661	lateral wash	Allen Canyon
92.2	3	648003	4125824	lateral wash	Montezuma Creek
84.1	3	635458	4127339	lateral wash	Recapture Creek
57.9	2	603144	4115670	lateral wash	Lime Creek
52.4	2	601301	4111310	lateral wash	Gypsum Creek
17.7	2	575497	4130142	lateral canyon	Slickhorn Canyon
16.4	1	573427	4130259	lateral canyon	river right
10.0	1	563449	4126456	lateral canyon	Buckhorn Canyon
8.1	1	561124	4128666	lateral canyon	Steer Gulch
3.3	1	553978	4127054	lateral canyon	river right

Table A-4. Summary of age-0 fishes collected in the San Juan River during the 2015 larval fish survey. Effort =8,886.4 m^2.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT OF TOTAL	CPUE[2]	FREQUENCY OF OCCURRENCE[3]	% FREQUENCY OF OCCURRENCE[3]
CARPS AND MINNOWS						
Red Shiner	I	77	0.4	0.87	15	5.1
Common Carp	I	15	0.1	0.17	9	3.1
Roundtail Chub	N	1	*	*	1	0.3
Fathead Minnow	I	236	1.3	2.66	49	16.7
Colorado Pikeminnow	N	24	0.1	0.27	5	1.7
Speckled Dace	N	1,034	5.8	11.64	86	29.4
SUCKERS						
Flannelmouth Sucker	N	12,176	68.5	137.02	162	55.3
Bluehead Sucker	N	2,912	16.4	32.77	91	31.1
Razorback Sucker	N	1,205	13.56	6.8	72	24.6
Razorback X Flannelmouth Sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
Black Bullhead	I	3	*	*	2	0.7
Yellow Bullhead	I	-	-	-	-	-
Channel Catfish	I	43	0.2	0.48	22	7.5
TROUT						
Kokanee Salmon	I	-	-	-	-	-
KILLIFISHES						
Plains Killifish	I	9	0.1	0.1	7	2.4
LIVEBEARERS						
Western Mosquitofish	I	41	0.2	0.46	21	7.2
SUNFISHES						
Green Sunfish	I	1	*	*	1	0.3
Bluegill	I	-	-	-	-	-
Largemouth Bass	I	9	0.1	0.10	8	2.7
TOTAL		17,787		200.16		

[1] N = native; I = introduced
[2] CPUE = catch per unit effort; value based on catch per 100 m^2 (surface area) sampled
[3] Frequency and % frequency of occurrence are based on *n* = 293 samples.
* Value is less than 0.05%

Table A-5. Summary of age-1+ fishes collected in the San Juan River during the 2015 larval fish survey. Effort =8,886.4 m^2.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT OF TOTAL	CPUE[2]	FREQUENCY OF OCCURRENCE[3]	% FREQUENCY OF OCCURRENCE[3]
CARPS AND MINNOWS						
Red Shiner	I	158	57.0	1.78	37	12.63
Common Carp	I	-	-	-	-	-
Roundtail Chub	N	-	-	-	-	-
Fathead Minnow	I	11	4.0	0.12	9	3.07
Colorado Pikeminnow	N	21	7.6	0.12	13	4.44
Speckled Dace	N	15	5.4	0.17	11	3.75
SUCKERS						
Flannelmouth Sucker	N	5	1.8	0.06	5	1.71
Bluehead Sucker	N	-	-	-	-	-
Razorback Sucker	N	-	-	-	-	-
Razorback X Flannelmouth Sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
Black Bullhead	I	1	0.4	0.01	1	0.34
Yellow Bullhead	I	-	-	-	-	-
Channel Catfish	I	3	1.1	*	3	1.02
TROUT						
Kokanee Salmon	I	-	-	-	-	-
KILLIFISHES						
Plains Killifish	I	2	0.7	*	7	0.68
LIVEBEARERS						
Western Mosquitofish	I	9	3.2	0.1	2	2.39
SUNFISHES						
Green Sunfish	I	1	0.4	*	1	0.34
Bluegill	I	-	-	-	-	-
Largemouth Bass	I	1	0.1	*	1	0.3
-						
TOTAL		227		2.55		

[1] N = native; I = introduced
[2] CPUE = catch per unit effort; value based on catch per 100 m^2 (surface area) sampled
[3] Frequency and % frequency of occurrence are based on *n* = 293 samples.
• Value is less than 0.05%

Table A-6. Scientific names, common names, and species codes of fishes collected in the San Juan River. Asterisk (*) indicates a species was collected in prior surveys but not in the 2015 larval fish survey.

Scientific Name	Common Name	Code
Order Cypriniformes		
Family Cyprinidae	**carps and minnows**	
Cyprinella lutrensis	Red Shiner	(CYPLUT)
Cyprinus carpio	Common Carp	(CYPCAR)
Gila robusta	Roundtail Chub	(GILROB)
Pimephales promelas	Fathead Minnow	(PIMPRO)
Ptychocheilus lucius	Colorado Pikeminnow	(PTYLUC)
Rhinichthys osculus	Speckled Dace	(RHIOSC)
Family Catostomidae	**suckers**	
Catostomus (Pantosteus) discobolus	Bluehead Sucker	(CATDIS)
Catostomus latipinnis	Flannelmouth Sucker	(CATLAT)
Xyrauchen texanus	Razorback Sucker	(XYRTEX)
Order Siluriformes		
Family Ictaluridae	**catfishes**	
Ameiurus melas	Black Bullhead	(AMEMEL)
*Ameiurus natalis**	Yellow Bullhead	(AMENAT)
Ictalurus punctatus	Channel Catfish	(ICTPUN)
Order Salmoniformes		
Family Salmonidae	**trouts**	
*Oncorhynchus nerka**	Kokanee Salmon	(ONCNER)
Order Cyprinodontiformes		
Family Fundulidae	**topminnows**	
Fundulus zebrinus	Plains Killifish	(FUNZEB)
Family Poeciliidae	**livebearers**	
Gambusia affinis	Western Mosquitofish	(GAMAFF)
Order Perciformes		
Family Centrarchidae	**sunfishes**	
Lepomis cyanellus	Green Sunfish	(LEPCYA)
*Lepomis macrochirus**	Bluegill	(LEPMAC)
Micropterus salmoides	Largemouth Bass	(MICSAL)

Table A-7. Covariates used in mixture models for Razorback Sucker.

Covariate	Description
Year	The calendar year in which the larval survey took place.
Reach	Each of the 5 geomorphic reaches (5–1) within the study area.
Habitat type	Backwater (BW), Embayment (EM), Run, (RU) Near Zero Velocity (NZV), Low Velocity (LV)>
Mean March, April and May temperature.	Daily mean temperature data was taken from USGS gage #09379500 near Bluff, Utah.
Mean March, April and May discharge.	Daily mean discharge data (cfs) was taken from USGS gage #09379500 near Bluff, Utah.
Annual # stocked.	The number of Razorback Sucker stocked within a calendar year. Fish stocked in a given year were used as a covariate for larval captures during the following larval survey year (i.e. 1+ overwinter periods).
Cumulative # stocked	The number of Razorback Sucker stocked during the time period between 1998 and the year prior to the larval survey year. (e.g. 5,000 fish stocked between 1998–2000 would be used as a covariate for 2001 larval capture data).
Fall monitoring captures.	All fall monitoring captures of adult Razorback Sucker. Fish collected during a given year were used as a covariate for larval captures during the following larval survey year (i.e. 1+ overwinter periods).

Table A-8. Covariates used in mixture models for Colorado Pikeminnow.

Covariate	Description
Year	The calendar year in which the larval survey took place.
Reach	Each of the 5 geomorphic reaches (5–1) within the study area.
Habitat type	Backwater (BW), Embayment (EM), Run, (RU) Near Zero Velocity (NZV), Low Velocity (LV)>
Mean June and July temperature.	Daily mean temperature data was taken from USGS gage #09379500 near Bluff, Utah.
Mean June and July discharge.	Daily mean discharge data (cfs) was taken from USGS gage #09379500 near Bluff, Utah.
Fall monitoring captures 400+ mm TL.	All fall monitoring captures of Colorado Pikeminnow greater than 400 mm TL. Fish collected during a given year were used as a covariate for larval captures during the following larval survey year (i.e. 1+ overwinter periods).

Table A-9. Summary of the age-0 Colorado Pikeminnow collected in the San Juan River during the 2015 larval fish survey.

Field Number	N=	Length (mm TL)	Ontogenetic Stage	Date Collected	Rivermile
MAF15-153	15	8.6 -9.4	mesolarvae	16-July-14	94.8
MAF15-155	4	8.8 -9.1	mesolarvae	16-July-14	92.6
MAF15-157	2	8.8, 9.7	mesolarvae	29-July-15	88.5
MAF15-162	1	9.2	mesolarva	30-July-15	79.3
JLK15-161	2	8.8, 9.3	mesolarvae	28-July-15	57.2
2015 Total	**24**				

Table A-10. Summary of the age-0 Razorback Sucker collected in the San Juan River during the 2015 larval fish survey.

Field Number	N=	Length (mm TL)	Ontogenetic Stage	Date Collected	Rivermile
JLK15-020	1	10.4	protolarva	24-April-15	122.6
JLK15-021	5	10.1 -12.5	proto - mesolarvae	24-April-15	119.8
JLK15-024	8	11 -11.5	proto - mesolarvae	24-April-15	118.3
JLK15-026	29	10.5 -11.9	protolarvae	24-April-15	116.7
JLK15-027	1	10.8	protolarva	24-April-15	113.4
JLK15-032	2	11.3, 11.6	proto - mesolarvae	25-April-15	102.5
JLK15-034	2	10.3, 11.5	proto - mesolarvae	25-April-15	98
JLK15-037	42	10.6 -12.7	proto - mesolarvae	25-April-15	92
JLK15-038	10	10.9 -11.8	proto - mesolarvae	25-April-15	89.6
JLK15-039	7	11 -11.8	mesolarvae	26-April-15	86
JLK15-041	21	9.6 -12.1	proto - mesolarvae	26-April-15	83.7
JLK15-042	2	10, 11.6	proto - mesolarvae	26-April-15	81.4
JLK15-043	5	10.4 -12.1	proto - mesolarvae	26-April-15	79.6
JLK15-044	12	10 -11.6	proto - mesolarvae	26-April-15	77.3
MAF15-001	1	11.9	protolarva	19-April-15	75.7
MAF15-003	2	10.9, 11.3	protolarvae	19-April-15	70.3
MAF15-007	1	N/A	N/A	20-April-15	59
MAF15-010	2	9.9, 10.3	protolarvae	20-April-15	56.1
MAF15-011	3	10.2 -11.3	protolarvae	20-April-15	52.8
MAF15-013	4	10.3 -11.1	proto - mesolarvae	20-April-15	50.3
MAF15-014	1	10.9	protolarva	21-April-15	48.8
MAF15-018	6	10.6 -11.6	proto - mesolarvae	21-April-15	35.2
MAF15-019	16	9.9 -11.7	proto - mesolarvae	21-April-15	32.1
MAF15-020	1	11.4	protolarva	21-April-15	28.2
MAF15-021	2	11.1, 13	proto - mesolarvae	22-April-15	24.7
MAF15-023	7	10 -11.6	proto - mesolarvae	22-April-15	18
MAF15-027	50	9.9 -14.6	proto - mesolarvae	22-April-15	14.4

MAF15-028	2	10.4, N/A	protolarvae	22-April-15	13.7
MAF15-033	6	10.4 -11.6	proto - mesolarvae	23-April-15	7.4
MAF15-034	22	10 -11.8	proto - mesolarvae	23-April-15	5
MAF15-036	1	11.2	protolarva	23-April-15	3.2
JLK15-048	17	10.4 -15	proto - mesolarvae	17-May-15	139.5
JLK15-049	3	14.1 -15.9	mesolarvae	18-May-15	135.5
JLK15-051	5	12.8 -15.6	protolarvae	18-May-15	133.3
JLK15-055	16	10.3 -15.7	proto - mesolarvae	18-May-15	128.1
JLK15-056	4	15 -18	mesolarvae	18-May-15	126.4
JLK15-058	4	14.7 -17	mesolarvae	19-May-15	122.5
JLK15-062	75	9.8 -17.9	mesolarvae	19-May-15	117.7
JLK15-063	33	10.5 -15.5	mesolarvae	19-May-15	116.9
JLK15-064	32	10.4 -16.4	mesolarvae	19-May-15	113.3
JLK15-065	1	12.4	mesolarva	19-May-15	107.6
JLK15-066	1	12	mesolarva	20-May-15	104.4
JLK15-067	25	12.5 -16.8	mesolarvae	20-May-15	100.5
JLK15-068	14	11.4 -17.1	mesolarvae	20-May-15	98.5
JLK15-070	5	10.8 -15.7	mesolarvae	20-May-15	92.2
JLK15-073	2	12.8, 14.7	mesolarvae	21-May-15	84.1
JLK15-074	15	12.5 -17.8	mesolarvae	21-May-15	79.4
JLK15-075	27	13.3 -17.3	mesolarvae	21-May-15	76.6
MAF15-040	2	13 -15.9	mesolarvae	18-May-15	67
MAF15-041	5	14 -16.6	mesolarvae	18-May-15	64.6
MAF15-042	17	11.2 -20	mesolarvae	18-May-15	59.8
MAF15-043	3	14.3 -16	mesolarvae	18-May-15	59
MAF15-044	5	13.3 -17.9	mesolarvae	18-May-15	57.9
MAF15-045	2	14.7 -16.5	mesolarvae	18-May-15	55.3
MAF15-046	120	10.9 -19.6	proto - mesolarvae	18-May-15	52.4
MAF15-050	116	11.1 -18.6	mesolarvae	19-May-15	41.2
MAF15-052	2	15.6, 26	meso - metalarvae	19-May-15	33.6
MAF15-055	14	10.4 - 17.4	proto - mesolarvae	20-May-15	26.8
MAF15-058	2	11, 15.8	mesolarvae	20-May-15	19.7
MAF15-061	1	15	mesolarva	20-May-15	17.7
MAF15-062	187	10.9 -22.4	meso - metalarva	20-May-15	13.9
MAF15-064	24	11.4 -19.2	mesolarva	21-May-15	10
MAF15-065	28	11 -22.4	proto - metalarvae	21-May-15	8.1
MAF15-066	1	17.1	mesolarva	21-May-15	7
MAF15-067	2	17.4, 16.9	metalarvae	21-May-15	5.6
MAF15-068	82	10.2 -20.5	proto - mesolarvae	21-May-15	4.2
MAF15-069	3	10.5 -21	proto - mesolarvae	21-May-15	3.3
MAF15-077	2	19, 21.8	metalarvae	16-Jun-15	124.8
MAF15-093	1	15.3	mesolarva	18-Jun-15	84.1
JLK15-085	1	11.1	mesolarva	15-Jun-15	52.4
Total	**1,205**				